Methodology to Estimate Pollutant Load Reductions

Final Report

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1.0 INTRODUCTION AND TMDL BACKGROUND

The federal Clean Water Act establishes a framework for protecting and restoring water quality based on the beneficial uses of each water body. Narrative and numeric water quality standards are established to protect these beneficial uses. Under Section 303(d) of the federal Clean Water Act, a water body that does not meet the established standards is considered water quality limited, or impaired, and is placed on a list of water bodies for which a Total Maximum Daily Load (TMDL) is required. Lake Tahoe is designated an Outstanding National Resource Water (ONRW) due to its extraordinary clarity. However, since 1968, scientists have measured a decline in water clarity at the rate of approximately one foot per year. The lake has been listed as “water quality limited” by the California Lahontan Regional Water Quality Control Board (Lahontan) and by the Nevada Department of Environmental Protection (NDEP). These two agencies are currently collaborating on a multi-phase TMDL program to better understand and protect the clarity of Lake Tahoe (NDEP and Lahontan, 2002).

A TMDL is a water quality restoration plan that is designed to reduce the pollution contributing to impairment. At Lake Tahoe, research has shown that it is the load, or mass, of fine sediment and nutrients that affects the long-term clarity trend, and not just the concentrations of pollutants in stream and storm water runoff. Phase I of the Lake Tahoe TMDL program involves conducting monitoring, analyzing data, conducting watershed and lake clarity modeling, and synthesizing information to develop a Technical TMDL for Lake Tahoe. Key elements include development and integration of a watershed pollutant load model and a lake clarity model. The objectives for this work are to estimate the pollutant loads from the watershed and to determine Lake Tahoe’s capacity to assimilate these loads while achieving water quality standards. Phase I of a three phase development process will establish targets for the pollutant load reductions necessary to maintain lake clarity.

Phase II of TMDL development is centered on the completion of an Integrated Water Quality Management Strategy that will explore various pollutant load reduction opportunities from major pollutant source categories (Upland, Stream Channel Erosion, Atmospheric Deposition, and Groundwater). The identification and acceptance of an integrated water quality strategy will form the basis for federally required pollutant load allocations that will establish milestones for pollutant load reduction and be reflected in the Implementation and Monitoring Plans to be developed as part of this phase. Once Phase II is completed, a Final TMDL will be developed that will include the work conducted as part of the first two phases of TMDL development. Phase III is intended to perform the adaptive management that will be needed to allow the tools and estimates developed for the TMDL program to continuously accommodate new research and information as needed. The third phase of the TMDL program will also need to track pollutant load reductions over time and provide credit towards milestones and allocations developed as part of Phase II.

The need to perform pollutant reduction tracking and allocation crediting was the impetus to begin work on developing a consistent methodology to estimate pollutant reductions from the implementation of water quality improvement projects. A fundamental premise of the TMDL program is that pollutant load reductions can be estimated with reasonable accuracy by using the tools developed in Phase II of the TMDL program (NDEP and Lahontan, 2003). The work described in this report is one step among many towards development of these tools. The estimates for load reduction are needed at several scales – individual water quality improvements, projects, and sub-watersheds or regions. The load reduction estimates will serve as the basis for determining how targeted load allocations and reductions will be met at the Lake Tahoe Basin scale.

The U.S. Army Corps of Engineers (Corps) is partnering with Lahontan to address this need and develop appropriate methodologies for estimating pollutant load reductions. The focus of this project is on pollutant load reductions primarily associated with storm water runoff in developed areas. It is the goal of the TMDL program to develop methodologies to address other pollutant sources (e.g., upland erosion, stream erosion, atmospheric deposition) and similarly track pollutant reductions occurring in other source categories. The development of methodologies from all source categories will take time and will need to be developed in such a way as to allow for continuous improvement and adaptation over time. The ultimate utilization of the collective methodologies will occur after approval of a Final TMDL in spring of 2009. The time between now and approval of a Final TMDL is intended to be used to both develop and refine identified methodologies. Consistent with this goal, the work completed as part of this report is intended to provide the first step toward the development and refinement of a tool to estimate load reductions resulting from the implementation of storm water improvement projects in developed areas of the Lake Tahoe Basin. The TMDL program is currently developing a process to include interested parties in the refinement and field testing of this methodology prior to the need for formal application in spring of 2009.

2.0 PROJECT SCOPE AND PURPOSE

The scope of work for this project is to develop, test, and compile methodologies that can be used to estimate or quantify pollutant load reductions from storm water quality improvement projects in developed areas of the Lake Tahoe Basin.

A methodology is ultimately needed that:

- Addresses different geographic scales (e.g., regional, project, individual BMP),
- Addresses the effects of both source controls and water quality treatment facilities,
- Addresses maintenance and monitoring effects,
- Focuses on pollutants of concern for Lake Tahoe (inorganic particulates <20 microns, nitrogen species, phosphorous species),
- Applies to different stages of project development (e.g., conceptual planning, watershed analysis, detailed design), and
- Can be adapted to support the future TMDL implementation system.

The intent of the project is to develop methodologies that are based on the current state of the science and engineering practice in water quality. However, the objectives listed above are ambitious and the information and data available to meet them are limited. The scope of work recognizes that the methodologies developed will necessarily rely on simplifying assumptions and estimated relationships to meet these objectives to the extent feasible, and will then recommend steps for future development and scientific support. A Project Advisory Committee

(PAC) consisting of representatives from the Corps, Lahontan, and UC Davis was established to guide the technical development and to assist in decisions regarding the scope of the project and future development. The compiled methodologies should be viewed as a "first step" towards the ultimate goal of pollutant load prediction in the Lake Tahoe Basin.

The scope of work for this project defines tasks and sub-tasks to investigate current practices within and outside the Lake Tahoe Basin that might be used as the basis for new methodologies; to screen, test, and develop methods; and to compile methodologies and develop example applications. Additionally, an important element of the project is to coordinate this work with the Lake Tahoe Basin stakeholders who will eventually apply or implement the methodologies.

The project is defined in three major tasks:

Task 1 - Investigate Local and Regional Water Quality Improvement Practices

The task is to investigate current practice in Lake Tahoe as a basis for future methodologies. This includes the following sub-tasks:

> 1a. Prepare interview forms and schedule interviews.
>
> 1b. Conduct fifteen (15) interviews to discuss BMP selection and design criteria; performance and regulatory standards to be met; analytical tools and data sources used; criteria for evaluating impacts and benefits; and maintenance and monitoring practices.
>
> 1c. Review current design and assessment practice for Lake Tahoe water quality controls.
>
> 1d. Recommend modifications to current water quality evaluation practice.

Task 2 - Summarize Existing Information and Programs at a National Level

This task involves research outside of the Tahoe Basin to identify analysis methods and pollutant load reduction methodologies that may be transferable, in whole or part, to the Lake Tahoe Basin with some modification. This includes the following subtasks:

> 2a. Review literature and distribute surveys. The literature review includes selected journal articles, research publications, professional association manuals of practice, reports from key state and regional storm water programs, reports from TMDL programs (e.g., Chesapeake Bay), and environmental compliance documents.
>
> 2b. Review and summarize national survey results. This subtask includes summarizing the results of the literature, and conducting and summarizing interviews with key researchers and practitioners across the country.

Task 3 - Develop Load Reduction Methodology

This task involves initial screening of methods, development and testing of new methods, compilation of methodologies at the various geographic scales required, and review with Lake Tahoe Basin stakeholders. This includes the following subtasks:

> 3a. Screen potential methods and methodologies. This includes screening of methods for evaluating source control effectiveness, volume effectiveness (e.g., capture ratios), and treatment effectiveness. It also involves evaluation of various computational approaches,

such as empirical estimates, statistical analysis, event-based modeling, continuous simulation, and hybrid approaches.

3b. Develop and test approaches. This includes development of methods based on available data, and testing the methods in the context of the Lake Tahoe Basin, including sensitivity to key input parameters.

3c. Compile methodologies. This includes conducting further development and testing of methods as part of overall methodologies; compiling recommended methodologies in guideline format (e.g., definition of analysis steps); identifying flexibility/variability to match preferred methods in use by implementers; identifying connections to other ongoing efforts (other elements of TMDL, SWQIC, Corps Hydrology Manual); identifying software development needed (technical tools), and prepare code to the extent feasible and determined appropriate by the PAC; and identifying input data needed and formats for use (e.g., MM5, GIS-based land cover data, regional hydrologic parameters, water quality relationships).

3d. Prepare examples. This includes preparing examples to demonstrate application of the methodology based on actual Lake Tahoe Basin settings and project types.

3e. Review methodologies with stakeholders. This includes a half-day review meeting and interviews with stakeholders, and discussion of the results with the PAC for incorporation into the draft report.

3f. Prepare report. This includes preparation of the draft report, presentation at a full-day stakeholders meeting, review with the PAC, and preparation of a final report.

Northwest Hydraulic Consultants and GeoSyntec Consultants were authorized on 10 December 2004 by the US Army Corps of Engineers (USACE) to begin work on a portion of Task 1. The remainder of Task 1, Task 2, and a portion of Task 3 (sub-tasks 3a-3d) were authorized 11 February 2005. The remaining sub-tasks of Task 3, included preparation of this report, were authorized 15 December 2005.

3.0 LAKE TAHOE WATER QUALITY IMPROVEMENT

The first task for developing a pollutant load reduction methodology was to conduct an investigation of local and regional water quality improvement practices. The investigation consisted of: 1) preparing an interview form, identifying a list of 15 interviewees and scheduling interviews; 2) conducting the interviews; 3) reviewing the interview results to evaluate Tahoe Basin water quality control design and assessment practices; and 4) recommending modifications to water quality evaluation practices.

The objectives of this task were to obtain information and opinions from a diverse group of regulatory and funding agencies, project implementers, and consultants; obtain insights into current practices and identify potential modifications to those practices to improve water quality design and assessment within the Tahoe Basin; and to compare current practices in the Tahoe Basin to the TMDL program goals. The interview responses were intended to help guide the development of a pollutant load reduction methodology.

3.1 Methods

An interview form was developed with input from the PAC that grouped questions into eight primary issues related to current water quality practices and implementation of the TMDL program. The form was provided to the interviewees prior to the interviews, with a cover letter describing the purpose of the current study. A brief description of the eight categories of questions is presented below. A copy of the interview form is provided at the end of Appendix C.

1. BMP Selection
Interviewees were asked to rank the importance of 13 elements related to BMP selection/evaluation by their organization. In addition, they were asked to discuss their five most important elements in greater detail. The purpose of these questions was to establish what factors significantly influence BMP selection within the Tahoe Basin.

2. BMP Design Criteria
A series of questions were posed that addressed BMP design details, such as design flows and volumes, BMP geometries, hydrologic criteria, soils and groundwater criteria, and relevant technical references. These questions were intended to highlight commonly used design criteria, as well as identify any innovative approaches currently used in the Basin.

3. BMP Design/Implementation Constraints
Several questions were asked in this section regarding project design constraints as they relate to concentration- or load-based water quality design, utilization of non-passive BMPs (e.g. chemical treatment), and land use. The responses provided insight into commonly-perceived difficulties in BMP design and implementation.

4. Typical Practices
The questions grouped together under this issue addressed typical BMP selection and design practices. Interviewees were requested to comment on their use of high-flow bypasses and treatment trains, as well as identify which BMPs they had previously selected for implementation one or more times.

5. Regulatory and Performance Standards

The interviewees were questioned about how regulatory and performance standards affect BMP design, including their opinions on the adequacy of these standards and a description of the types of calculations performed to demonstrate compliance. The responses helped identify the most- and least-frequently applied standards.

6. Analytical Tools and Data Sources

This category covered project information sources, as well as application of hydrologic and water quality design tools. Interviewees were also asked to identify any other tools that might be useful for individual BMP or project design purposes.

7. Maintenance and Monitoring Practices

A group of questions was posed to the interviewees regarding their maintenance and monitoring practices, including type performed, and schedule and reporting requirements. Questions were also asked about whether, and if so how, monitoring results were utilized in BMP design.

8. Summary

The final section focused on identifying methodologies to estimate project effectiveness with regard to pollutant load reduction during the design phase. Interviewees were asked whether they were aware of any such methodologies being applied inside or outside the Tahoe Basin.

3.2 Compilation of Interview Results

The results of the interviews were compiled into tabular format in order to provide a condensed summary of the responses. An effort was made to report the responses as directly as possible, without added interpretation of the respondent's statements. When several respondents answered in a similar manner, however, their comments were typically reduced into a single response that best represented their statements. For some questions, information about the number and type of respondents was included to better quantify the answers. Responses are summarized in this report, but not attributed to particular individuals or agencies. Appendix C includes:

1. A list of interview participants by agency/firm;
2. A summary of responses organized by category;
3. Tabulated responses for each question; and
4. The interview form.

3.3 Summary of Lake Tahoe Water Quality Practice

Lake Tahoe Basin water quality analysis and design practices are summarized below based on the interview findings and interpreted in the context of methodologies needed to support implementation of the TMDL program.

3.3.1 Computation of Pollutant Load Reductions and Project Effectiveness

A major purpose of the interviews was to gain insight into methodologies that are currently in use that might be adapted to the needs of the TMDL program. In particular, the computation of pollutants loads and load reduction were of interest. Although many of the interview respondents identified runoff volume and peak flow reduction as typical project design parameters, fewer indicated detailed experience with calculation of pollutant concentration or load reductions, on either an event or long-term basis. Several respondents referred to calculation of concentration reductions. However, follow-up questions to most of these responses indicated that this is not a normal project design procedure and many of the calculations were actually very simplified estimates used for relative comparisons with low levels of confidence. Only one project was identified (the Tahoe City Constructed Wetlands project) in which post-project pollutant concentrations were estimated using methods supported by water quality references or literature.

Several respondents stated that pollutant load reductions were sometimes estimated, but none of the responses indicated that a particular level of treatment in terms of load reduction was used as a standard for design. Examples typically involved application of estimated BMP efficiencies and relatively simple empirical methods for estimates of total sediment load reduction (e.g., application of Universal Soil Loss Equation [USLE]). Several respondents referred to application of a spreadsheet method in the Formulating and Evaluating Alternatives (FEA) guidance document (SWQIC, 2004), but recognized that the method estimates load by land use and does not explicitly account for load reduction due to source controls or treatment. No examples of detailed pre- and post-project pollutant load calculations for fine sediment or nutrients from an entire project area were identified.

At the individual BMP level, most respondents were aware of references such as the International BMP database (www.bmpdatabase.org), but expressed a low confidence in the quality of the data. Only a few respondents indicated experience with continuous hydrologic modeling or pollutant load modeling, although several expressed interest in such techniques. The EPA's SWMM and HSPF models were mentioned, but generally not considered standard technical tools. One respondent indicated they use WEPP to estimate pre- and post-project erosion. One consultant referred to use of a proprietary watershed management model, but noted difficulties in estimating BMP efficiencies, characteristics of runoff from land uses, and other factors.

At the scale of typical water quality projects, the task of estimating pollutant load reductions is complicated by the number of facilities involved and variability in their design due to site and funding constraints. The majority of water quality projects in the Tahoe Basin are retrofits of public facilities in areas of existing development. New development occurs at a very slow pace, and the design of water quality facilities for these areas is subject to a high degree of regulation. Private property BMP retrofit standards have been adopted by TRPA and include specific hydrologic standards that prevent discharge of runoff and pollutants to the public drainage system in most hydrologic events. Unfortunately, implementation of these standards has occurred only in a few areas, and timing for completion of the BMP retrofit on private property is generally considered uncertain by implementers of public works projects.

In contrast to new development and private property, water quality design for public facilities in areas of existing development is reviewed by regulatory agencies with a "best practicable" approach that is nearly always affected by site or funding constraints. This is reflected in the interview responses from implementers, which cite various practical constraints as key design factors. A typical grant-funded erosion control project in the Lake Tahoe Basin involves improvement of sub-standard roadway and drainage facilities that were likely constructed 20 to

50 years ago. Therefore, much of the project funding necessarily is used for drainage facilities and roadside collection facilities (e.g., concrete curb and gutter, drop inlets, etc.). These improvements control roadside drainage to prevent erosion in the shoulder areas and stabilize drainage courses to reduce fluvial erosion. However, project funding is rarely sufficient to treat every potential erosion source at a uniform or standard level, and site constraints (especially land availability) typically limit the options for water quality treatment facilities.

Several related factors affect the difficulty faced in current practice for estimating pollutant load reductions for these types of projects:

1. The current approach in the design of public water quality projects, generally referred to as the Preferred Design Approach, emphasizes source control and hydrologic control (reduction of runoff) over treatment facilities (CTC, 2002; SWQIC, 2004). Although the probable effectiveness of this approach is supported by national and international storm water management research and practice, it makes the problem of estimating load reductions complex. A wide range of source control and hydrologic controls are likely to be combined with various treatment measures, and their application is at least influenced, if not controlled, by site and funding constraints. This may result in non-uniform performance of the source and hydrologic controls, and causes uncertainty in inflowing concentrations and loads to treatment facilities. This presents an extremely complex problem at the project scale.
2. There are not uniform standards, design criteria, or practices for design or implementation of BMPs in the Tahoe Basin that can be used as the basis for estimating characteristic concentrations or treatment effectiveness. Caltrans (2002) provides planning and design guidance for a limited set of BMPs. Typical project designs are heavily influenced by project experience and site constraints, and reviewed with the "best practicable" approach. The 20-year, 1-hour volume standard is typically targeted, but this only applies to volume-based treatment improvements and is typically calculated using the impervious area in the right-of-way of the project area. These calculations may not take into account flows generated on pervious surfaces, flows from impervious surfaces outside the right-of-way, or flows from upstream areas. All of these can be significant factors that affect the actual performance of water quality projects.
3. Load reduction estimates for retrofit of existing development areas are generally more difficult than for areas of new development. A load estimate for a newly developing area, for example, might be made with a characteristic concentration or concentration-discharge relationship based on the development standards to be applied. Load reduction through a regional treatment BMP (e.g., water quality basin) might then be developed using a unit process or empirical relationship for the treatment BMP. In contrast, land use conditions are not likely to be nearly so uniform in a typical Tahoe Basin water quality improvement project area and improvement standards (both pre- and post-project) are generally not uniform. Acceptance by landowners, noted as one of the factors in project success by interview respondents, can significantly affect selection of project measures and overall project performance.
4. Quantitative information on sources of pollutants or characteristic concentrations in terms of land use or land conditions is limited in availability. Recently, water quality

improvement projects have begun to use characteristic concentrations to estimate pollutant loads (FEA spreadsheet) on a regular basis. This methodology was adopted by the Storm Water Quality Improvement Committee (SWQIC, 2004) and is based on Tahoe Basin monitoring data developed by the Tahoe Research Group for various land use types (Reuter, et al 2002 and Heyvaert, et al 2003). However, the FEA spreadsheet is based on very simple hydrologic estimates of flow-duration characteristics, and the representative land use concentrations available may not reflect specific project area conditions. Typically, projects change the land use conditions (e.g., stabilize roadside shoulders, revegetate, construct drainage systems, etc.) but do not change land use types. Therefore, the characteristic concentrations by land use are not suitable for estimating source reductions from these projects, and compilation and analysis of additional data for this purpose appears to be extremely limited. Characterization of changes in pollutant sources is especially important as project designs are considered at the watershed or sub-watershed scale, a practice encouraged by the Preferred Design Approach.

5. Typical hydrologic estimates made for Tahoe Basin projects are generally not sensitive enough to estimate the change in runoff volumes and rates that may occur due to typical improvements of drainage collection and conveyance systems. In many cases, no estimate of the change in annual runoff volume or flow-duration characteristics is made for water quality projects. Although these types of estimates are more common than pollutant load estimates, the problem is complex and confidence in the results of typically applied hydrologic models is low. Therefore, potential tradeoffs between decreased sources of pollutants and increased loads associated with higher volumes or rates of runoff from improved drainage systems are difficult to quantify.

6. Pollutants of concern for the Lake Tahoe TMDL are fine sediment and nutrients. Although information on sources of sediment (in general) and the effectiveness of BMPs to reduce sediment loads are limited, the data is much more available than information on sources and transport of fine sediment (e.g., less than 20 microns) and nutrients. This is especially true for the dissolved fraction of the nutrient loads and transformations that may occur between chemical species in drainage and treatment facilities.

7. Water quality project facilities are typically maintained by public works departments and improvement districts. The major current sources of water quality-related grants provide funds for construction but not maintenance of facilities. Although most implementers have a systematic maintenance program, the effects of limited maintenance funds on BMP performance is not known. The limited funding also clearly influences the types of improvements that are currently practical.

8. Due to the position of the developed areas around the lake margin, project areas typically have limited available area for storm water runoff mitigation and are frequently subject to flows from upstream areas with low levels of development. However, these areas may be disturbed to some degree, either by current or historical land use practices. These areas have land use and hydrologic conditions that are very different from the more developed areas. Because land use and hydrology are two factors that drive pollutant loads, and because implementation of improvements is significantly constrained by land use, different methodologies may be appropriate for these two major classes of Tahoe Basin

lands. The relative magnitude of loads, as well as relative potential for improvement, will be important for allocation of load reductions.

9. Water quality improvement strategies at the project scale are influenced by opportunities such as discharge to existing wetlands or stream environment zones after some level of pre-treatment. These approaches are generally considered beneficial by both implementing and regulatory agencies as a way to provide enhanced treatment or "polishing" of storm water discharges. However, the level of treatment obtained in this manner has not been quantified and is probably highly variable depending on site conditions, discharges, and pollutant loading.

Given the complexities listed above it is not surprising that pollutant load reduction computations have generally not been considered practical at a project scale. Standard methodologies are not currently required (or offered) by the regulatory and grant funding agencies and project permitting is considered a difficult task by implementers. In the course of a normal project, the development, application, and negotiation of a numeric load reduction methodology is not practical. Nevertheless, most implementing agencies and their consultants express a desire to use more standardized and quantitative methods to streamline the process of designing and permitting water quality improvement projects. The interview results indicate that little is available from existing Tahoe Basin practice that can be adapted directly to the needs of the TMDL program to estimate pollutant load reductions at the necessary scales. Tahoe Basin experience in the application of water quality models or other analytical techniques for pollutant load reductions appears to be very limited.

3.3.2 Pollutants of Concern for Lake Tahoe

An understanding of the sources, transport, and transformation of Lake Tahoe pollutants of concern (fine sediment and nutrients) is key to TMDL load reduction. The interview results indicate a mixed view of the importance of understanding these processes in selecting and designing water quality projects. Additionally, the actual performance for removal of pollutants of concern is rarely quantified. This likely reflects the recognized scientific uncertainty and desire on the part of the implementers to avoid protracted debate on these subjects at the project level. Instead, both implementers and consultants emphasized site constraints in designing BMPs, and to experience in previous projects. The responses to the question about successful projects contained primarily qualitative measures, with little reference to monitoring results and no distinction between pollutants. Although responses indicated that project designs had sometimes been modified based on monitoring results, very few examples were given that indicated direct use of numeric monitoring data in design for pollutants of concern. Visual monitoring was noted as a basis for design modifications by most respondents.

In general, estimated effectiveness in sediment removal seems to be considered a surrogate for most pollutants, although responses to some questions (e.g., treatment train use) indicated a general approach toward use of vegetated BMPs for nutrient removal. No standard numeric techniques were identified for nutrient load removal estimates. Quantitative estimates for nutrient removal were cited for only a few projects. The computation of project reductions in nutrient loads is generally considered beyond the scope of typical water quality improvement project design, and consideration of the differences between dissolved and total nutrient loads is yet another step removed from practical design considerations.

The identification of fine particulates as a significant concern is a relatively recent development, consequently very little monitoring data is available on particle size distributions in runoff that can be used to estimate fine sediment loads or effectiveness of BMPs and water quality improvement projects. Caltrans (2003) characterized particle size distributions from sediment collected in highway sand traps, but this may not represent highway runoff characteristics or runoff from other land use types. In general, few respondents indicated that distinctions between sediment loads and fine sediment loads had significant influences on design other than to size facilities to be as large as possible within site constraints.

The Lahontan and TRPA effluent discharge standards were frequently referred to by respondents as unachievable or unrealistic. Although the effluent concentrations are recognized as the regulatory standards, they are not used as the basis of design. The lack of connection between regulatory standards and design criteria is the source of considerable frustration for the implementers.

The interviews indicate a general recognition that fine sediment and nutrients are pollutant of concern for Lake Tahoe, but current practices appear to place little emphasis on numeric estimates or performance standards for load reductions of specific pollutants.

3.3.3 Optimization of Water Quality Improvements

Optimization methods are potentially applicable to the TMDL load reduction methodology to maximize load reductions or to consider cost-benefit relationships. Interview responses indicate that little is currently done to optimize water quality performance using load reduction estimates. For example, selection of basin draw-down times was frequently based on vector control requirements rather than modeled or measured treatment performance. A few respondents indicated that site conditions and particle settling criteria were considered to maximize treatment for volume-based controls. Similarly, design of high flow bypasses is common, but in most cases does not appear to be based on specific optimization criteria or monitoring information.

Most respondents indicated experience with a wide range of BMP types, but considered site constraints or previous experience as the key factors in selection. Where optimization occurs, it generally appears to be based on qualitative assessments of potential project components. If optimization is to be included in the load reduction methodology, this information will likely need to be developed from hydrologic and water quality modeling with little Tahoe Basin calibration data.

3.3.4 Institutional and Practical Constraints

Site and funding constraints were identified prominently in the interview responses on current design practices. Implementation of the TMDL may require fundamental changes in funding or design approaches that could substantially change these constraints. However, for the purpose of this project, the prominence of site constraints in the current design process emphasized the desirability of a methodology that has the flexibility to account for variability in design and implementation storm water improvement projects. The ability of the methodology to account for variable site conditions, sizes, and BMP designs, either in the work for this project or in the future, was seen as a highly desirable attribute for the methodology. Further, the interviews indicate that the ability to simultaneously estimate the application of various combinations of BMPs in a project area, including application at different levels of intensity, was desirable.

3.3.5 Technical and Information Gaps

Interview results indicate significant gaps in the technical basis for design of storm water quality improvement projects to meet specific pollutant load reduction objectives. Current practice focuses on selecting the best practicable water quality improvements given site constraints, and project designers apply limited quantitative estimates for pollutant load reductions. Most interview respondents seem receptive to a more quantitative methodology based on available information and reasonable assumptions, if adopted by regulatory and funding agencies. The TMDL program will contribute significantly to closing many of the technical gaps, but it is anticipated that uncertainty in quantitative estimates will remain high for some time. In spite of this uncertainty, adoption of a quantitative methodology could provide a more systematic basis for collection of information and data specifically relevant to Tahoe Basin practices and conditions. This information can then be used to improve estimation methods and support adaptive management of implementation efforts.

3.4 Recommendations

Current practices in the Lake Tahoe Basin are neither state-of-the-art with regard to water quality analysis nor very efficient with regard to implementation of water quality projects. This situation is at least partly the result of a lack of standard approaches and design criteria, including a lack of connection between numeric effluent standards, pollutant reduction requirements, and design. Implementing agencies have no consistent set of design criteria for water quality projects, and design staff and consultants must navigate the review and regulatory process by demonstrating that the design is the best practicable given constraints. This practice is nearly always subject to qualitative interpretation, resulting in lengthy project delivery times and uncertain results in water quality performance.

The implementation of the TMDL as a regulatory standard presents an opportunity to standardize approaches and streamline the delivery of water quality improvement projects. Based on the interview results, several associated elements were identified that would benefit the implementation of the TMDL program:

1. A BMP design manual is needed to standardize design criteria based on water quality performance. This manual should include estimates of load reductions and/or effluent concentrations achievable using specified design criteria, or a range of criteria. Simple design criteria (e.g., runoff volume/drawdown time combinations) should be used where appropriate based on Item 3) below, or its successors. Caltrans has funded and developed a statewide planning and design guidance document (2002) and effluent concentration relationships for selected BMPs that meet the design criteria (2004). This approach may be a useful example for development of a Lake Tahoe Basin BMP design manual.

2. A hydrologic design manual should be developed and adopted that provides guidance for both conveyance/storage design and water quality design criteria. Continuous hydrologic simulations should provide the basis for water quality performance and optimization analysis. This is consistent with the watershed modeling basis for the Technical TMDL, and standardized methods should be adopted that provide consistent results at a range of scales.

3. Pollutant load reduction estimates should be based on the pollutant load reduction methodology initiated in this project, and coordinated with Items 1) and 2) above. Pollutant load reduction estimates should be completed for each major project and for all pollutant of concern.

4. A monitoring strategy should be developed to provide the necessary feedback to adjust Items 1) through 3), and monitoring data should be compiled in a format useful and accessible to designers.

5. A prioritization method should be developed for Tahoe Basin water quality improvement projects based on pollutant loads from the TMDL program, and considered in grant funding programs. Estimated pollutant load reductions from projects should be a factor in establishing priorities.

6. A method should be developed for assessing the effects of private property BMP retrofits on pollutant loads to public facilities, and a realistic schedule for implementation should be developed so that load reductions can be estimated.

Development of approaches and design criteria should recognize the considerable uncertainty involved in load reduction estimates and plan for refinement as new information becomes available. Although individual agencies or designers might undertake any of the tasks listed above, significant progress is unlikely without adoption of standardized, basin-wide approaches. Unless standard approaches and design criteria are adopted regionally, it will likely remain impractical for project implementers to develop and apply them on a project-by-project basis.

4.0 NATIONAL WATER QUALITY IMPROVEMENT

This section summarizes a literature search and national interview process conducted with researchers and water quality program implementers across the country. The purpose of this work was to summarize existing information and programs on a national level regarding pollutant load reduction estimation methodologies, especially as applicable to TMDLs.

The amount of information on pollutant load reductions at a national scale is too extensive to complete an exhaustive survey within the time and resources allocated to this task. Therefore, the work was focused by developing a list of prominent programs and researchers, performing initial contacts and interviews, and following up when potentially applicable information was discovered.

4.1 Methods

The literature search was focused on key subject areas for computation of pollutant loads and load reductions. Approximately 130 publications were catalogued into a database to allow sorting, searches by keywords, and reporting. A portion of the catalogued literature is listed in Appendix E.

A preliminary list of interview candidates was developed and reviewed with the PAC. Interview questions were prepared to guide discussions, but the project team focused the interviews individually to obtain information most relevant to the project in a short time. Interviews lasting approximately one hour were conducted by telephone over a period of approximately two weeks. Individual interview summaries are included in Appendix D.

4.2 Literature Search

Storm water runoff quantity and quality and BMP performance for some BMPs can be estimated using physically-based, process-driven models (i.e., analytical/deterministic), as well as probability-based, data-driven models (i.e., empirical/stochastic). Regardless of the method used, modeling of pollutant loads discharged from a project site or area of interest to a common discharge point requires the estimation of storm water runoff volumes and pollutant concentrations.

There are a variety of methods available for reducing pollutants in runoff including pollution prevention, site design, source controls, and storm water treatment. Pollution prevention is a means of preventing the pollutant from entering the environment in the first place and most notably includes product substitution (e.g., removing lead from gasoline, using least toxic pesticides, etc.). Site design refers to practices that protect or restore the native vegetation and soils so as to maintain, to the extent feasible, the natural water balance.

Source controls are defined in this report using two categories: pollutant source controls and hydrologic source controls. Pollutant source controls limit the supply of pollutants on the watershed and therefore limit the potential for certain pollutants to be mobilized and transported during a storm event. Common examples of pollutant source control are revegetation and street sweeping. Hydrologic source controls limit runoff by retaining or providing for the natural processes of interception, infiltration, and evapotranspiration. Site design and source controls are an important part of any storm water management system and improve the performance of downstream treatment BMPs. Modeling of some site design and most source controls is difficult due to a scarcity of data on performance. The most feasible controls to model are those associated with hydrologic source controls - for example, reduced impervious areas or reduced connectivity of these areas to a drainage system.

Storm water treatment is often the major and final line of defense for improving water quality and quantity before storm water runoff reaches the receiving water. Modeling the performance of many structural source controls and storm water treatment BMPs requires estimating the inflow rates and volumes in relationship to the size of the control (i.e., volume captured) and estimating volume losses and effluent quality (i.e., pollutant removal). The modeling components for predicting storm water quantity, quality, and resulting pollutant loads are shown in Table 4.1.

Table 4.1 - Water Quality Modeling Components

Modeling Category	Modeling Components	
Pollutant Generation	Hydrology: Storm water runoff rates and volumes	Water Quality: Storm water runoff pollutant concentrations
Pollutant Reduction	Source Controls: Prevent and reduce storm water runoff volumes and reduce mobilization of pollutants during a storm	Storm Water Treatment: Remove pollutant from storm water runoff and to a lesser extent also reduce storm water runoff volumes

All water quality models or methods to predict storm water runoff volumes, pollutant concentrations, and resulting pollutant loads must contain the components shown in Table 4.1, but many simplifications are in use. For example, the Simple Method (Schueler 1987; Ohrel 2000) is an empirical export coefficient approach developed for estimating annual runoff volume and pollutant loads using a modification of the Rational Method. The method predicts runoff volumes instead of flow rates (as traditionally predicted by the Rational Method) and uses storm water quality monitoring data for different land uses for pollutant concentrations.

Several hydrologic methods are available for estimating storm water runoff quantity and quality. Fewer methods are available for quantifying the reduction of pollutants in storm water treatment BMPs, and the effects of pollutant source controls is the most challenging aspect of storm water quality modeling. Each of the primary modeling components is described in detail below, with accompanying citations provided in Table 4.2 corresponding to the literature review list in Appendix E.

4.2.1 Pollutant Generation

TMDLs are usually written in terms of the acceptable load that may be discharged to a water body without exceeding the water quality standard, including a margin of safety to reflect uncertainty and future growth potential. TMDLs may be expressed in terms of a given mass of pollutants over a certain time period (e.g. pounds per day, year, or season). The product of storm water volume and storm water pollutant concentration is the pollutant load, typically on a storm event or an average annual basis. TMDLs can also be expressed in terms of concentrations, especially where the concern is aquatic or human health toxicity. In a few cases, TMDLs have been expressed as percent reduction goals (e.g., TSS in forest management). Because the TMDL in Lake Tahoe will be related to loads, estimates for both runoff hydrology and quality are of interest.

4.2.1.1 Hydrologic Modeling: Storm Water Volumes

Runoff volumes and rates are typically used for making load estimates, for sizing storm water treatment BMPs, and for estimating influent quality to a BMP. Some common runoff hydrology methods include the Rational Method (on which the so-called "simple method" is based), variable source areas, unit hydrograph, regression analyses, and water balance methods (i.e. more process-based hydrologic models). Variations on the rational method and synthetic unit hydrograph approaches are commonly applied in the Lake Tahoe Basin to estimate runoff rates and volumes from design storm events for project design. Process-based or continuous modeling is much less common at the project scale.

Modified Rational Method: The Rational Method predicts the peak runoff rate (volume of runoff / time) from the rainfall intensity, tributary area and a runoff coefficient. The runoff coefficient is usually estimated based on the fraction of the impervious cover or types of land uses in the tributary area. The estimate of the runoff coefficient does not incorporate detailed watershed information (e.g. soil types, land use or cover, vegetative cover, or antecedent conditions) into the estimation of this parameter, unless the estimate is based on actual monitoring data.

An adaptation to the traditional rational method is the concept of the volumetric runoff coefficient which is the ratio of total runoff to total rainfall. This coefficient also is usually estimated based on imperviousness or land use. For example, both the EPA (1983) and FHWA (1990) have developed regression relationships for runoff coefficients vs. percent imperviousness based upon extensive monitoring of a large number of watersheds.

SCS Curve Number Method: The SCS curve number method predicts the runoff rates from an equation that incorporates the effects of interception and depression storage (the amount of rainfall that is not available for runoff at the beginning of a storm), land use type, general cover condition and hydrologic soil group. The peak runoff rate and hydrograph are estimated with a time to peak equation (comparable to the time of concentration for the Rational Method). Although the method is designed for a single storm event, it is sometimes scaled to estimate average annual runoff volume. SCS curve numbers are also used in several lumped parameter water quality models for predicting surface runoff volumes including SWAT, AGNPS, CREAMS and GWLF (Lyon et al. 2004).

Variable Source Areas: The concept of variable source areas (VSAs) is based on the assumption that only saturated pervious and impervious areas contribute to direct runoff. With this approach the amount of water required before runoff from pervious areas begins is equal to the porosity per unit area of the shallowest soils in the watershed, which are the zones fringing streams and creeks. Modeling the spatial extent and temporal fluctuation of a VSA is based on a water balance approach and depends on a number of hydrological and morphological factors like rainfall intensity, soil texture, water table depth, and topographic attributes of the terrain (Hernandez et al. 2003).

Unit Hydrograph: The unit hydrograph is a simple linear, event-based method for deriving the direct runoff hydrograph from a watershed. A unit hydrograph is defined as the surface runoff hydrograph resulting from a unit depth (usually 1 inch or 1 centimeter) of excess rainfall. Unit hydrographs are generally derived from stream-flow data or synthesized using standardized unit hydrographs (e.g., SCS, Clark, Snyder) and the characteristics of the watershed. The direct runoff hydrograph is created by applying the unit hydrograph to the hyetograph of excess rainfall. A hyetograph is a graphical representation of the amount of precipitation that falls through time. The flood hydrograph is generated by superimposing the resulting hydrographs and adding the estimated base flow to the direct runoff hydrograph. The Santa Barbara Unit Hydrograph (SBUH) is an adaptation of the unit hydrograph method. The SBUH method was developed to determine a runoff hydrograph for an urbanized area by computing a hydrograph directly (in contrast to building up the hydrograph from a superposition of unit hydrographs) to determine the runoff hydrograph.

Regression Analyses: Different descriptive variables for a watershed can be regressed versus storm water runoff data to derive a relationship for predicting future runoff volumes. The impervious area of a watershed is probably the most commonly used parameter for urban watershed studies, but slope, elevation, relief, aspect, soil properties, vegetation properties, stream order, drainage density, and flow length are examples of other parameters that could be used if a statistically significant regressive relationship is found. This method requires storm water flow monitoring and watershed characterization data to perform the analysis. Diver and Tasker (1990) completed a national analysis of urban runoff monitoring sites to establish such relationships.

Process-Based Methods (hydrologic system models): A wide array of models exist that are based on simulating varying levels of complexity in hydrologic processes for modeling runoff from watersheds or urban areas. These are typically continuous simulation models (i.e., operating on a long time series of input data through several storm events or years) rather than single storm event models, and some have capabilities for simulation of snowmelt. Many of these models also have the capacity to simulate water quality. For a thorough review of water quality models refer to Fitzpatrick et al. (2001). A few examples of the many models available include:

- Better Assessment Science Integration Points and Nonpoint Sources (BASINS), USEPA
- Hydrologic Simulation Program FORTRAN (HSPF), USEPA;
- Source Loading and Management Model (SLAMM), Dr. Pitt University of Alabama;
- Storm water Management Model (SWMM), USEPA & Oregon State University.
- Storage, Treatment, Overflow Model (STORM), USACE–HEC, and CDM

Process-based hydrologic models use actual or synthetic rainfall data as the primary model input and predict storm water runoff rates based on parameters representing physical processes in the modeled watershed. These models typically account for losses due to infiltration and evapotranspiration and are capable of generating more accurate hydrographs than the alternative methods based on empirically-derived coefficients (e.g. flow rates will vary with rainfall, rather than assuming uniform rainfall and flows). Due to their physical basis, these models typically require more input parameters and are therefore more time and data intensive. Where data are limited, the results may be improvements over more empirical methods. Continuous simulations (i.e., continuing through many precipitation events and intervening dry periods) are common for many of these models.

Continuous simulations differ from event-based hydrologic modeling in that they generally rely on a longer time series of representative meteorological data that may extend over many storm events or years. Continuous simulations track the water balance in various hydrologic processes (e.g., evapotranspiration, infiltration, storage) to produce a time series output for runoff. This runoff time series can then be analyzed statistically to determine design parameters such as peak flow-frequencies or flow-duration probabilities. In contrast, event-based methods normally require defining a set of watershed antecedent conditions and statistical interpretation of precipitation depth-duration-frequency to define a particular design event prior to simulation (e.g., 100-year, 24-hour event; 20-year 1-hour event, etc.). The advantage of event-based simulation is that input requirements and calibration are normally simpler. The advantage of continuous simulation is that actual or synthetic meteorological data can be used directly without statistical interpretation, and that variations in runoff due to changing antecedent or watershed conditions can be inherently accounted for in the simulation. Output from continuous simulations can also be used to look at variability in runoff patterns with season, dry and wet years, differences in storm patterns, and other hydrologic variables.

Table 4.2 - References for Storm Water Runoff Volumes Estimates

(Reference number is keyed to literature catalogue in Appendix E)

Method	**References**
Modified Rational Method	EPA, 1983 #134; Driscoll et. al. 1990 #135; Schueler, 1987 #136
SCS Curve Number	Mishra, S.K., Jain, M.K., and Singh, V.P. (2004) #113 Ferguson, B.K. (1996) #114 Steenhuis, T.S., Winchell, M., Rossing, J., Zollweg, J.A., and Walter, M.F. (1995) #117
Variable Source Areas	Bernier, P. Y. (1985) #89 Valeo, C. and Moin, S.M.A. (2000) #97 Steenhuis, T.S., Winchell, M., Rossing, J., Zollweg, J.A., and Walter, M.F. (1995) #117 Lyon, S.W., Walter, M.T., Gerard-Marchant, P. and Steenhuis, T.S. (2004) #127 Hernandez, T., Nachabe, M., Ross, M., and Obeysekera, J. (2003) #128
Regression Analysis	Brezonik P.L. and Stadelmann T.H. (2002) #16, Driver, N.E. and Tasker, G.D. 1990) #105
Water Balance (Hydrologic Models)	Reuter, J.E. (2003) #55 Reuter, J.E., Heyvaert, A.C., Luck, M. and Hackley, S.H. (2001) #79 Noguchi, M.; Hiwatashi, T.; Mizuno, Y.; Minematsu, M. (2002) #90 Vaze, J. and Chiew, F.H.S. (2003) #91 Pandit, A. and Gopalakrishnan, G. (1997) #92 Al-Abed, N.A. and Whiteley, H.R. (2002) #98 Tsihrintzis, V.A., Fuentes, H.R., and Gadipudi, R.K. (1997) #99 Frankenberger, J.R., Brooks, E.S., Walter, M.T., Walter, and M.F., Steenhuis, T.S. (1999) #101 Driver, N.E., and Tasker, G.D. (1990) #105 Jain, M.K., Kothyari, U.C., and Ranga Raju, K.G. (2004) #116 Singh, J., Knapp, H.V., and Demissie, M. (2004) #118 Shamsi, U.M. (1996) #126
Snowmelt hydrology	Semadeni-Davies A (1998) #15

Method	References
	Bengtsson L. and Singh V.P. (2000) #17 Feng X.H., Taylor S., Renshaw C.E. and Kirchner J.W. (2002) #19 Taylor S., Feng X.H., Renshaw C.E. and Kirchner J.W. (2002) #20 Ho, C-L. (2002) #74
Flood Frequency	Crompton, J.E., Glen, W.H., Williams, R.P. (2002) #38

4.2.1.2 Water Quality Modeling: Storm Water Pollutant Concentrations

Several methods are available to predict storm water quality (see Fitzpatrick et al. (2001) for a thorough review of commonly used water quality models). Some of the more common approaches are land use-based methods (e.g., the simple method), build-up / wash-off methods, soil erosion and transport methods, and TSS partitioning methods. It is widely accepted that pollutant concentrations vary throughout a storm event and certainly over the course of a year, but often data is limited on how pollutant concentrations vary between storm events and within storms. Some approaches account for variation in pollutant concentrations during a storm event (pollutograph). However, many approaches use a single value (e.g., the event mean concentration or EMC) as the water quality characteristic for all storm events. The EMC represents the mean of sampled storm water concentrations through a single event.

Land use-based methods: The increased availability of urban storm water quality data, such as those contained in the International BMP database (www.bmpdatabase.org), allow the estimation of pollutant concentrations based on land use type. This type of estimate usually does not account for variation in storm water pollutant concentrations, but instead uses a mean EMC to represent the average pollutant concentration in storm water runoff in storm events. The EMC is typically lower than the pollutant concentrations observed in the initial portion of a storm event runoff (i.e. the first flush) and higher than concentrations in the tail end of the storm. Simple land use-based approaches can be improved by accounting for the uncertainty of pollutant EMCs by using a random statistical sampling method known as the Monte Carlo method (Coats et al. 2002 and Zou et al. 2002).

Build-up / wash-off methods: Build-up / Wash-off methods predict pollutant accumulation during dry periods and wash off during storm events. Pollutant accumulation can be based upon parameters such as type of land use (including surrounding land uses and associated activities), pollutant source controls (e.g., street sweeping between storms) and atmospheric deposition to estimate the rate of pollutant accumulation. Wash-off is typically a function of parameters such as rainfall intensity, watershed slopes, and pollutant particle sizes (e.g. sediment sizes) to estimate the mobility (i.e. entrainment and transport) and subsequent wash-off of pollutants.

However, it has been recognized that Build-up/Wash-off methods cannot explain all of the sources of pollutants in runoff and that if this method is used alone it can result in errors. For example, the effectiveness of street sweeping in a model that uses build-up/ wash-off as the sole route for pollutants entering storm water will often result in a large over-prediction of its effectiveness. If build-up/ wash-off is used, it needs to be combined with other source introduction methods (such as soil erosion, rainfall sources, etc.) which then requires significantly more data than is typically available.

Soil erosion and transport methods: Soil loss equations such as the widely used Universal Soil Loss Equation (USLE) and variations thereof (Revised Universal Soil Loss Equation [RUSLE] and Modified Universal Soil Loss Equation [MUSLE]) predict the erosion of topsoil based on soil erosion potential, rainfall or runoff erosion energy, runoff path length, slopes, cover, and erosion control practices. This type of method is most often applied to agricultural and open space areas and construction sites where sediment loss is of primary concern. It is used less often for urban areas where other pollutant source introduction processes are prevalent and impervious areas and landscaping prevent or minimize erosion from significant watershed areas. However, some models that are applied to both urban and non-urban areas, like the EPA's HSPF model, incorporate sediment erosion and transport routines.

TSS partitioning methods: Many common storm water pollutants, such as trace metals, oil and grease, phosphorus, and pesticides have low solubility in water and tend to adsorb or absorb strongly to sediments in runoff. The exceptions are pollutants such as chloride and other ions (from road salts for example), and most forms of nitrogen (nitrate, nitrite, ammonia). Partitioning methods model TSS and predict pollutant concentration using some type of multiplier based on empirical observations. However, the relationships between TSS and other pollutants are highly site specific. These methods require site specific data for development of the relationships that are then only applicable for that site.

Table 4.3 - References for Storm Water Quality Characterization

(Reference number is keyed to literature catalogue in Appendix E)

<table>
<tr><th colspan="2">Method</th><th>References</th></tr>
<tr><td rowspan="5">Loads Models</td><td>Non-proprietary models / model comparisons</td><td>Reuter, J.E., Heyvaert, A.C., Luck, M. and Hackley, S.H. (2001) #79
Noguchi, M.; Hiwatashi, T.; Mizuno, Y.; Minematsu, M. (2002) #90
Vaze, J. and Chiew, F.H.S. (2003) #91
Zhang, J., Haan, C.T., Tremwel, T.K., and Kiker, G.A. (1995) #93
Driver, N.E., and Tasker, G.D. (1990) #105
Kalin, L., and Hantush, M.M. (2003) #106
Srivastava, P., Hamlett, J.M., and Robillard, P.D. (2003) #107
Chui, T.W., Mar, B.W., and Horner, R.R. (1982) #109
Cassell, E.A. and Clausen, J.C. (1993) #120
Whittemore, R. and Ice, G. (1999) #121
Ohrel, R.L. (2000) #125</td></tr>
<tr><td>CSM</td><td>Pandit, A. and Gopalakrishnan, G. (1997) #92</td></tr>
<tr><td>GIS</td><td>Osborne, K.G. (2000) #94
Tsihrintzis, V.A., Fuentes, H.R., and Gadipudi, R.K. (1997) #99
Dartiguenave, C.M. and Maidment, D.R. (1997) #102
Melancon, P.A., Maidment, D.R., and Barrett, M.E. (1999) #103
Quenzer, A.M. (1998) #108</td></tr>
<tr><td>SLAMM</td><td>Pitt, R and Voorhees, J. (2002) #95
Pitt, R., Liburn, M., Durrans, S.R., Burian, S., Nix, S., Voorhees, J, and Martinson, J. (1999) #96</td></tr>
<tr><td>BASINS</td><td>Tong, S.T.Y and Chen, W. (2002) #104</td></tr>
<tr><td rowspan="2">Land-use Based</td><td>Urban</td><td>Brezonik P.L. and Stadelmann T.H. (2002) #16</td></tr>
<tr><td>Highway</td><td>Caltrans (2002) #11</td></tr>
</table>

Method		References
	Sediment and/or Nutrient Sources (Tahoe)	Dogrul, E.C., Kavas, M., Levent, Aksoy, and Hafzullah. (2001) #8 Reuter, J.E., Heyvaert, A.C., Luck,M., Hackley, S.H. (2001) #9 Reuter, J.E., Heyvaert, A.C., Hackley, S.H. (2000) #10 Hatch L.K., Reuter J.E., Goldman C.R. (1999) #27 Hatch L.K., Reuter J.E., and Goldman C.R. (2001) #29 Reuter, J.E. (2003) #55 Reuter, J.E., Heyvaert, A.C., Luck, M. and Hackley, S.H. (2001) #79 Hydro Science (1999) #80 Reuter, J.E. and Miller, W.W. (2000) #81
Build-up / Wash-off		Zug, M., Phan, L., Bellefleur, D., and Scrivener, O. (1999) #110 Deletic, A., Maksimovic, C., and Ivetic, M. (1997) #111 Winter, J.G. and Duthie, H.C. (2000) #112
Soil Erosion		Kalin, L., and Hantush, M.M. (2003) #106 Qin, H., S.J. Burian, and F.G. Edwards (2004) #131

CSM = Continuous Simulation Method
GIS = Graphical Information System
SLAMM = Source Loading and Management Model
BASINS = Better Assessment Science Integrating Point and Nonpoint Sources

4.2.2 Pollutant Reduction

Pollutant reductions in storm water runoff can be achieved through minimization of runoff volumes and pollutant loads (source controls) and maximization of pollutant removal in storm water treatment BMPs. The available monitoring data on source controls is often insufficient to simulate these practices in water quality modeling. However, inclusion of source control BMPs is an important factor in the overall performance of a storm water management system.

4.2.2.1 Pollutant Prevention: Source Controls

Source controls are described in this report using two categories: pollutant source controls and hydrologic source controls. Pollutant source controls limit the supply of pollutants on the watershed and therefore limit the potential for certain pollutants to be mobilized and transported during a storm event. Hydrologic source controls limit runoff by retaining or providing for the natural processes of interception, infiltration, and evapotranspiration. Some examples for each type include:

Pollutant Source Controls:

- Stabilize disturbed areas and hillslopes to decrease erosion;
- Regularly sweep pavement between storm events;
- Minimize application of roadway traction abrasives;
- Stabilize and improve conveyance systems to decrease erosion;
- Properly store and apply fertilizers and pesticides.

Hydrologic Source Controls:

- Minimize impervious areas by incorporating landscaped areas over substantial portions of the project area and construct streets, sidewalks and parking lot aisles to the minimum widths allowed;
- Leave adequate areas to preserve the existing riparian areas to protect stream health;
- Drain rooftops and driveways to landscaped areas to promote infiltration;
- Utilize pervious or indirect drainage systems.

The efficacy of source controls is more difficult to quantify because of the lack of information on the effects of source controls on improving runoff quality, and the fact that most models do not address specific sources or the effects of a limited supply of pollutants. The deficiency in available source control information is common to both Lake Tahoe Basin research and national research.

4.2.2.2 Pollutant Removal: Storm Water Treatment BMPs

The reduction in pollutant load and concentration achieved by a storm water treatment BMP depends on the portion of the runoff treated and the extent of treatment achieved. Effective BMP performance depends on various factors including selecting treatment appropriate to the pollutants of concern, sizing the BMP to treat the majority of runoff while safely bypassing the highest flows / volumes, and maintaining the BMPs.

A variety of methods have been utilized in BMP monitoring studies to evaluate efficiency and subsequently estimate BMP performance, many of which are briefly described below. For a thorough discussion of these methods and their benefits and limitations see the EPA report Urban Performance BMP Monitoring (Strecker et al., 2002). The following describes alternative metrics that are used to measure pollutant removal effectiveness.

<u>Efficiency Ratio</u>: The efficiency ratio is derived from the reduction in pollutant event mean concentration relative to the influent event mean concentration.

<u>Summation of Loads</u>: This method of determining removal efficiency is based on the ratio of effluent to influent loads (rather than concentrations) for the BMP.

<u>Regression of Loads</u>: This method uses linear least squares regression of the effluent pollutant loads to the influent loads with the intercept constrained to zero. The removal efficiency is equal to unity minus the slope of the regression.

<u>Mean Concentration</u>: The mean concentration is estimated from the ratio of the average effluent concentration and influent concentration. This method does not flow weight the concentrations to estimate EMCs.

<u>Efficiency of Individual Storm Loads</u>: This method calculates the removal efficiency for a BMP as the average of the removal efficiencies for individual storms. The result for each storm is based on the influent and effluent loads (similar to summation of loads).

<u>Effluent Quality</u>: This method first compares the influent and effluent distributions to test for a statistically significant difference, i.e. if pollutant removal is occurring. The effluent distribution is used to characterize the performance of the BMP.

<u>Reference Watersheds</u>: This method estimates the load reduction between a test watershed where BMPs have been installed versus a control watershed. This method is applied for BMPs without a clearly defined inlet or outlet like porous pavement and infiltration practices and street sweeping. Difficulty in controlling other variables within the test watershed can make determining BMP effectiveness difficult.

References in Appendix E contain key words that have been used to identify those references that address pollutant removal efficiency and BMP performance and design (Table 4.4).

Table 4.4 - References for Pollutant Removal Efficiency and BMP Performance and Design

Method		References
BMP Models	Non-proprietary models / model comparisons	Kalin, L., and Hantush, M.M. (2003) #106 Srivastava, P., Hamlett, J.M., and Robillard, P.D. (2003) #107 Winter, J.G. and Duthie, H.C. (2000) #112 Cassell, E.A. and Clausen, J.C. (1993) #120 Whittemore, R. and Ice, G. (1999) #121
	GIS	Osborne, K.G. (2000) #94 Dartiguenave, C.M. and Maidment, D.R. (1997) #102 Melancon, P.A., Maidment, D.R., and Barrett, M.E. (1999) #103 Xue, R.Z., Bechtel, T.J., and Zhenquen, C. (1996) #123
	SLAMM	Pitt, R and Voorhees, J. (2002) #95 Pitt, R., Liburn, M., Durrans, S.R., Burian, S., Nix, S., Voorhees, J, and Martinson, J. (1999) #96
	Watershed Studies	Park, S.W., Mostaghimi, S., Cooke, R.A., and McClellan, P.W. (1994) #122
Tahoe BMP Feasibility		Reuter, J.E. (2003) #55
Performance and/or Design	Wetlands	Braskerud, B.C. (2002) #2 Wittgren, H.B. and Maehlum, T. (1997) #3 Tanner C.C., Sukias J.S. and Upsdell M.P. (1998) #6 Kadlec, R.H. (1999) #7 Moustafa, M.Z. (1999) #30 Heyvaert, A.C., Reuter, J.E., and Hackley, S.H. (2001) #56 Hydro Science (1999) #80 (*treatment meadows*)
	Multiple BMPs	Reuter, J.E., Heyvaert, A.C., Luck, M. and Hackley, S.H. (2001) #79 Lenhart, J.H. (2004) #133
	(Dry) Extended Detention Ponds	Newman, T.L. II, Omer, T.A., and Driscoll, E.D. (1999) #115 Shammaa, Y., Zhu, D.Z., Gyurek, L.L., and Labatiuk, C.W. (2002) #119
	Swales & Filter Strips	Abu-Zreig, M., Rudra, R.P. and Whiteley, H.R. (2001) #100
	Sand Traps	Caltrans (2002) #11
	ATT	Nissen, J. (2002) #49

GIS = Graphical Information System
SLAMM = Source Loading and Management Model
ATT = Advanced Treatment Technologies

4.3 Interviews with Researchers

Phone interviews approximately one hour in length focused on the following topics:

- Load generation methodologies,
- Load reduction methodologies, and
- BMP design criteria.

Each interviewee tended to have somewhat different research interests, and this likely contributed to their different perspectives on the above discussion topics. The subsequent sections are an overall synthesis of the interviews within each of the discussion topics. The interested reader is strongly encouraged to read the summary of the interviews contained in Appendix D for more detail. Table 4.5 lists the storm water practitioners and researchers interviewed.

Table 4.5 - Research Interviews

Affiliation	Interviewee	Position
Wisconsin Department of Natural Resources	Roger Bannerman	Environmental Specialist
Center for Research in Water Resources, University of Texas at Austin	Michael Barrett, Ph.D., P.E.	Research Professor
University of Alabama at Tuscaloosa	Robert Pitt, Ph.D., P.E.	Professor of Civil and Environmental Engineering
Colorado State University, Fort Collins	Larry Roesner, Ph.D., P.E.	Professor of Civil and Environmental Engineering
University of Florida	John Sansalone, Ph.D., P.E.	Professor of Civil and Environmental Engineering
Villanova University, Pennsylvania	Robert Traver, Ph.D., P.E.	Professor of Civil and Environmental Engineering
Denver Urban Drainage and Flood Control District	Ben Urbonas, P.E.	Chief

4.3.1 Load Generation Methodologies

The researchers agreed that loads, to be most meaningful, should represent a range of conditions that called for a continuous, or at least annual approach, rather than a discrete event perspective. Barrett pointed out that data and assumptions usually limit our ability to accurately model runoff loads for specific events, and felt that annual runoff loads based on annual precipitation, a simple rainfall runoff relationship, and land use based water quality data is adequate for most purposes. Barrett was a strong voice for simplicity given what he perceived as the difficulty of implementation at the local level. A number of researchers (e.g., Roesner, Pitt) supported a continuous modeling approach that takes into account the sequence of storms, wet vs. dry years, and the effects of infiltration and evapotranspiration on the water balance. The researchers tended to rely on empirical land use data for modeling water quality, rather than analytical methods such as the pollutant buildup wash-off concept, or if using the latter, identified (Traver) a definite need for calibration data and data on other source mechanisms (e.g. rainfall scrubbing, roof runoff, etc.).

Specific modeling recommendations followed from their own research and experience, including the Storage, Treatment Overflow Model STORM (Roesner); the EPA's Storm Water Management Model SWMM (Urbonas); and the Source Loading Assessment and Management Model SLAMM (Pitt, Bannerman). These models represent an ever increasing level of detail and therefore data requirements.

Few interviewees had information on load generation during snowmelt. Sansalone reported a study in which one of his students is compiling a snowmelt water quality database using snow samples from Lake Tahoe. Sansalone also reported some water quality data collected from runoff from parking lots in Lake Tahoe area during snowmelt periods.

The researchers all indicated the need for an adaptive management approach by which initial estimates would have to be field verified, with subsequent changes in modeling assumptions and inputs. All agreed that loads from instream sources (channel erosion) were potentially important, and some of the researchers were evaluating these types of sources and attempting to come up with criteria to minimize loadings from the effects of hydromodification (Roesner). Although there are a number of models that could potentially address sediment transport (e.g., HSPF), none were aware of models, such as those listed above, that addressed instream loading of pollutants other than sediment.

4.3.2 Load Reduction Methodologies

The researchers indicated that the hydrologic contribution to load can be more accurately estimated compared to the concentration contribution to load. This is because the hydrologic performance of most BMPs is well understood and captured in many hydrologic models. For example, the volume of runoff that is capable of being diverted into a BMP (sometimes referred to as percent capture), and the volume of water that is either infiltrated or evapo-transpired within the BMP can be reasonably predicted with hydrologic models.

However, methodologies for estimating load reduction associated with water quality improvements tend to be more empirical and depend to a large extent on observed data which is commonly not site specific or design specific. The empirical nature of load reduction methodologies makes it difficult to estimate load reduction for BMPs in series or BMPs that are designed as retrofits (where design is dictated more by constraints, than by meeting some standard). Barrett points out that, in his experience, BMPs in series tend to modify the need for maintenance of the more downstream facilities, rather than necessarily result in improved performance. When addressing the performance of BMPs in series, Barrett has in the past assigned a correction factor to the percent removals of the BMPs such that the first BMP might achieve 100% of the removal estimate for that type of BMP for the constituent of concern, but the second would only get credit for say 50% of the removal that it might achieve if it were 1st in the treatment train.

One alternative to addressing the load reduction associated with concentration changes, as discussed by Sansalone, is to try to develop a statistically reliable database relating flow to loads and then rely on flow estimates to make load reduction predictions. Sansalone also suggested that simple kinetic type equations that incorporate the effects of influent quality on performance could, in principle, be used to analyze treatment trains.

Bannerman works in Wisconsin where there are many lakes undergoing eutrophication from excess phosphorus loads. He has quantified the effectiveness of source controls such as fertilizer and phosphorus bans using SLAMM. He pointed out that detention alone is not sufficient in his state to restore lakes, and is strongly recommending BMPs that incorporate infiltration, filtration (as in rain gardens), and enhanced settling (flocculation).

4.3.3 BMP Performance Standards

Researchers were asked their opinions of performance standards that could be used as basis for BMP design. The researchers were informed that the current practice in Lake Tahoe is often based on the 20-year 1-hour rainfall.

Urbonas and Bannerman stated that a uniform performance standard may not be required, but rather an overall goal should be set. Parallels to the current TMDL effort in Lake Tahoe were evident. For example, Bannerman pointed out that in one Wisconsin lake management plan, the goal was to achieve the clarity of the lake as measured in 1955. The advantage of a goal like this is that it is understandable by the public, compared say to a goal specifying the concentration of *chlorophyll a*. This clarity goal could then be translated into a load reduction goal that then could be tracked as projects are implemented. This approach is particularly suitable in retrofit situations where site constraints may make it difficult to meet a uniform standard. Traver reinforced this concept where retrofit designs are based on available land.

Roesner was a proponent of using continuous modeling to set the performance standard. Examples he cites were the 80-85th percent capture methodologies (i.e., design facilities to treat 80-85 percent of mean annual runoff) as contained in the California Storm Water BMP Manual or contained in the Water Environment Federation Manual of Practice 23 titled 'Urban Runoff Quality Management."

Barrett pointed out that whatever is used should be simple to apply, even if based initially on complex modeling. He pointed out that in the City of Austin, one performance standard merely specified the volume of runoff required to be captured based on the percent imperviousness of the site. Sansalone warned about over reliance on the first flush concept for setting a performance standard.

Questions also were asked regarding setting a performance standard for hydromodification control. In the state of Pennsylvania, Traver pointed out a dual control approach addressing flow as well as water quality control. Roesner discussed his research looking at maintaining pre-development flow frequency curve to manage hydromodification. Roesner also pointed out that the same facilities could be used for water quality, hydromodification, and flood control, and that such facilities also could be in line, rather than offline as commonly considered.

4.4 Interviews with Programs

Twelve agencies in various parts of the United States were contacted to gather information about their pollutant load and load reduction estimation methodologies. These agencies were selected based on their engagement in active storm water-related TMDL or other water quality improvement programs. Additional information was collected about TMDL program structure and management to provide a context for the types of estimates each agency performed. The interviewees are presented in Table 4.6, and observations from the interviews are briefly summarized in four categories below. Full interview summaries for the most relevant programs are provided in Appendix D.

Table 4.6 - Program Interviews

Agency	Interviewee	Position
Chesapeake Bay Program – EPA	Rich Batiuk Gary Shenk	Asst. Director for Science Environmental Scientist
Florida Department of Environmental Protection	Jan Mandrup-Poulsen Douglas Gilbert Eric Livingston	Administrator Environmental Manager Chief, Watershed Mgmt Program
Kansas Department of Health and Environment	Tom Stiles	Chief, Bureau of Water

Agency	Interviewee	Position
Lake Champlain Basin Program	Eric Smeltzer	Environmental Scientist
Maine Department of Environmental Protection	David Halliwell	Maine Lakes TMDL Program Manager
Maryland Department of Environmental Protection	Elaine Dietz	TMDL Outreach Coordinator
Minnesota Pollution Control Agency	Greg Johnson	Senior Hydrologist
New York Department of Environmental Conservation	Ron Entringer	Chief, Source Protection Section
Ohio Environmental Protection Agency	Trinka Mount	TMDL Coordinator
South Carolina Department of Health and Environmental Control	Kathy Stecker	Section Manager of Watersheds and Planning
Texas Natural Resource Conservation Commission	Ward Ling	Project Manager
Wisconsin Department of Natural Resources	Jim Baumann	Special Assistant to Director of Watershed Management

4.4.1 Summary of Program Interviews

1. Description of Agency TMDL Programs
   The programs ranged in size from small agencies that contracted most of their work out to very large agencies with several hundred staff members. Most state programs are responsible for developing multiple TMDLs throughout their jurisdiction. The state programs therefore often emphasize standard procedures and methodologies designed to expedite the processing of numerous studies in many different watersheds, rather than developing procedures specific to a particular watershed or water body.

   The Chesapeake Bay Program is the exception to this rule, encompassing extremely large management and modeling efforts specific to a single watershed. As part of the program, an organizational structure has been developed to manage the interactions of the federal government, academic personnel, eight state governments and hundreds of individual communities. In addition, numerical models have been developed for the 64,000 square mile watershed and the bay itself.

   Most programs have a defined process for the establishment of TMDLs, which vary in the details, but generally adhere to the following process: 1) assessment of pollutant loadings from the watershed, based on water quality monitoring and modeling; 2) development of a numeric TMDL and target allocations; 3) development of an implementation plan (not all agencies do this); 4) validation of water quality improvement through monitoring; and 5) responding to changes in water quality through adaptive management, as necessary. Most programs defined a process for developing and implementing action plans to address load reductions, although several agencies pointed out that this is not required by federal law. Several programs cited past lawsuits as affecting or driving their TMDL development schedule. A number also noted that parts of the TMDL evaluation process had been codified into state regulations, which gave them more leverage in developing and implementing TMDLs.

2. Program Management
   The TMDL programs identified through the interview process are typically managed by a single agency. A few programs are jointly managed by multiple state agencies or state and

federal agencies, including those in Texas and New York. The Chesapeake Bay Program is managed by a regional partnership formed by primary representation from Maryland, Virginia, Pennsylvania and the District of Columbia, and with technical oversight by the EPA.

Most programs are funded primarily by federal grant money, although a few noted that about half their funding comes from state revenues. In New York, New York City pays for work performed within their municipal watershed. The primary stakeholders on TMDL projects were typically identified as local governments, agricultural interests, private property owners and environmental associations.

3. Technical Approaches to Determining Loads and Load Reductions

The agencies interviewed use a range of approaches to determine pollutant loads and pollutant load reductions. The most simplified approaches included the use of export coefficients and flow-duration curves to calculate pollutant loads. More moderately-intensive estimation methods involved the application of empirically-based watershed models such as the Generalized Watershed Loading Function (GWLF) and the Watershed Management Model (WMM), and the development of comprehensive flow and load accounting models using standard spreadsheet software. The most sophisticated approach identified for determining pollutant loads was application of the Chesapeake Bay Watershed Model. This model is based on the continuous-simulation model HSPF and divides the 64,000 square mile watershed into 94 segments that become smaller in size closer to the bay. This Chesapeake Bay Program's level of modeling effort requires a tremendous amount of data, personnel, and money to support.

Calculation of pollutant load reductions was very limited among the agencies interviewed. Only one agency, the Chesapeake Bay Program, regularly applies BMP effectiveness to calculate a load reduction. The Bay Program has established performance estimates for approximately 40 standard BMPs – these are aggregated by subbasin and included in their watershed model. The BMP performance estimates were developed by consensus through a 'tributary strategy workgroup'. Several other agencies interviewed have occasionally applied BMP performance estimates to determine pollutant load reductions. Florida stated that they have used a range of BMP performance estimates on projects where a spatially disaggregated watershed model has been developed, and New York has used the standard BMP performance estimates included in GWLF. Some states noted that they used surrogates to estimate the effectiveness of their implementation plans. But a number of states reported that BMP effectiveness was not considered at all, primarily due to lack of reliable information on BMP effectiveness. Only the Chesapeake Bay Program, of all the agencies interviewed, had established an approach to include estimated retrofit BMP effectiveness in their watershed modeling.

About half the agencies interviewed have had some involvement with pollutant trading or offsets. Pollutant trading appears to be very limited, with one or two trades reported at most. Only two agencies referenced written guidelines on pollutant trading: the Chesapeake Bay Program uses EPA guidelines on trading and the Florida Department of Environmental Protection is in the process of developing their own pollutant trading guidelines. Several agencies reported that they expected to do more pollutant trading in the future as regional development and growth continues.

4. Program and TMDL Improvements
   The agencies were asked to identify factors that worked well in their current programs, as well as identify areas where there was room for improvement. Processes reported as functioning well included:
   - group management in the Chesapeake Bay Program; this facilitated decisions that were supported by all of the major stakeholders
   - building load allocations into state water quality planning regulations
   - use of a basin-wide permitting strategy
   - use of a defined process that the public understands

   Factors that were listed as causing difficulties:
   - consensus-based decisions may only reach the lowest common-denominator
   - states have a difficult time planning for water quality improvements over long time spans
   - concerns that TMDLs are not based on adequate data
   - difficulty getting the public engaged until late in the process because they do not think the program affects them

   Virtually every agency has a feedback cycle in place to evaluate the effectiveness of their TMDLs and implementation plans. They also have monitoring plans in place to test water quality and most used the terminology of 'adaptive management' to describe the process of re-evaluating the status of their impaired waters, and either re-visiting their implementation plans or de-listing a water body.

4.4.2 Approaches to Calculating Pollutant Loads

Through the interview process, several different approaches to calculating pollutant loads were identified. These varied in level of complexity, from simple literature-based export coefficients to advanced continuous simulation models. Examples of each type of approach identified during the interview process are provided in this section to illustrate the range of potential methodologies available to determine pollutant loads.

The range of approaches evaluated is summarized in categories defined as simplified, moderate, and advanced. For reference, the Lake Tahoe TMDL is a sophisticated approach that combines continuous watershed modeling of pollutant loads and lake clarity modeling, based on the best available scientific methods and data. For this project, simpler methods are desirable for ease of implementation at the project scale, and more complex methods are desirable to the extent that they are needed to be consistent with and to support a sophisticated and adaptable TMDL. Because of these objectives, information was compiled for a broad range of approaches.

4.4.2.1 Simplified Approaches

Export Coefficients:

The Maine Department of Environmental Protection uses a procedure based on export coefficients to estimate phosphorus loads to lakes.

1. Develop a land use inventory for the watershed, using categories such as various agricultural practices, classifications of shoreline development, classifications of non-shoreline development and surface water (for atmospheric deposition).
2. The impacts of shoreline residential developments are rated from 1 to 5. These are based on ground-truthing, with 1 being the least impacted (natural condition) and 5 being the most impacted. A rating of 1 is assigned to lots with a full naturally vegetated shoreline buffer, while a rating of 5 is assigned to lots with bare dirt at the lakeshore. Other factors impacting water quality are investigated as well, including seasonal versus full-time residency, presence of retaining walls and lot slope.
3. The information on shoreline impacts is distilled into a water quality rating of 'low', 'medium' and 'high'. Each lot is then subjectively assigned a phosphorus export coefficient from the manual "Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development" (Maine DEP, 1992).
4. Total loads are determined by multiplying the export coefficient by the area of each lot, roadway or other area of concern to get pounds of pollutant per year.

Flow Duration Basis:

The Kansas Department of Health and Environment utilizes a simplified approach to estimating and regulating pollutant loads based on flow duration curves.

1. A mean daily flow duration curve is developed for a site of interest. This can be done either directly from gage data, or indirectly with data derived by ratios with a nearby gaged watershed.
2. The flow duration curve is then multiplied by the water quality concentration standard and a conversion factor to create a load duration curve in pounds per day.
3. Water quality monitoring sample concentrations are converted to daily loads by multiplying the concentration by average daily flow. The loads are then plotted on the flow duration curve. Samples plotting above the load duration curve are out of compliance, while samples plotting below the load duration curve are in compliance.
4. They feel comfortable applying this method in watersheds of 50 to 100 square miles in area, and non-urbanized watersheds.

4.4.2.2 Moderate Approaches

Several moderately-intensive modeling approaches to developing pollutant loads were identified. These models are empirical and require a fair amount of localized input data.

Generalized Watershed Loading Function (GWLF):

The Ohio Environmental Protection has used the Generalized Watershed Loading Function (GWLF) model to generate pollutant estimates within a number of their watersheds. GWLF simulates hydrology using the Natural Resource Conservation Service's Curve Number method and mechanistically models pollutant loads, including pollutant build-up and wash-off. It runs as a continuous simulation model with a daily timestep for water balance calculations; that accounts for evapotranspiration, subsurface flow volumes, and surface flow volumes. GWLF requires a set of relatively simple inputs, such as land use information, soils data, and parameters related to runoff, erosion, and nutrient load generation. GWLF was originally developed at Cornell University, but has been adapted for use in both Pennsylvania and Ohio; localized parameters would need to be established for application of GWLF in other parts of the country. The GWLF modeling approach is defined as follows:

1. The watershed is divided into sub basins for modeling purposes. Factors considered in subbasin delineation include the balance between simplicity and detail, availability and location of water quality data, existence of stakeholder groups, and hydrologic units.
2. Land use/land cover within the watershed is classified into 12 categories; these are further grouped into "urban" and "rural" categories for modeling purposes.
3. Standard NRCS soils information is obtained and hydrologic soils groups are assigned to each soil type.
4. Local or regional daily precipitation data is used for hydrologic calibration of the model, if possible.
5. A series of input values are defined, including runoff curve numbers, evapotranspiration cover coefficients, soil water capacity, recession and seepage coefficients, rainfall erosivity, soil erodibility factor, length-slope factor, pollutant build-up rates, and cover and management practice factors.
6. Two other pollutant sources are added to the model if applicable: septic systems (defined as either functional or failing) and point sources.
7. The model is run to determine daily loads of the pollutants of concern.

<u>Watershed Management Model (WMM):</u>
The Florida Department of Environmental Protection (Florida DEP) has used several forms of the Watershed Management Model (WMM) on TMDL projects. WMM is designed to estimate seasonal or annual pollutant loadings from non-point sources within a specified watershed. User inputs include land use coverages, percent imperviousness by land use, event mean concentration (EMC) by pollutant type and land use, and annual precipitation. An adjustment is typically made for directly connected impervious areas to ensure that runoff is not overestimated. WMM has several limitations: it is not suitable for short-term load estimates (daily, weekly, etc.), nor should it be used to evaluate the effects of relatively small changes within a watershed (affecting less 10% of the area). Florida has also re-created the computational engine used in WMM in a standard spreadsheet to provide more control and flexibility in their modeling efforts. The general approach to using WMM-based models is as follows:

1. Applicable annual precipitation and evaporation data are collected.
2. Sub-basins are delineated and land use coverage is gathered in GIS. Land use is generally categorized in the 10 default categories within WMM.
3. The area served by septic tanks is determined, if applicable.
4. The percent impervious in each land use category is determined; this is a key component of WMM-based models.

5. Event mean concentrations (EMC) are determined for each pollutant type and land use category. Florida DEP prefers to use local values if available, followed by regional values and lastly literature values.
6. Any point source flows and pollutant concentrations are identified.
7. Calibration is typically conducted for both runoff volumes and water quality.
8. Once the model is calibrated, land use values are set to undeveloped conditions to determine historical loads. Final target loading levels are established from an understanding of historical loads and an estimate of a water body's assimilative capacity.

4.4.2.3 Advanced Approaches

The most advanced water quality modeling approaches identified for load calculations were all variations of the continuous-simulation model HSPF. While the Chesapeake Bay Program appears to have implemented one of the largest applications of an HSPF-based model, other agencies have also applied similar models, including WARMF in South Carolina and HSPF in Texas.

<u>Chesapeake Bay Watershed Model:</u>
The Chesapeake Bay Program has developed a continuous-simulation model of the 64,000 square mile Chesapeake Bay watershed. The Chesapeake Bay Watershed Model is closely based on HSPF and has been gradually expanded and developed over the last 20 years. The current version, Phase 4.3, continuously simulates 17 years of data at an hourly timestep, using 94 model segments and 9 defined land use categories. The model segments range in size from very large headwater sub basins to small urbanized catchments closer to the bay; sub-areas are typically on the order of 100 square miles. HSPF allows integrated modeling of hydrologic routing and physical and chemical water quality processes. Sediment export is determined empirically, based on volumes of detached sediment and runoff intensity. Nutrient export can be modeled using either an empirical procedure or a mechanistic procedure. The Chesapeake Bay Watershed Model has been calibrated to the 1984-1995 time period for both hydrology and water quality. Model outputs, in the form of daily flows and nutrient and sediment loads, are applied as inputs to the Chesapeake Bay Estuary Model. Results are often reported as long-term (10-year or more) average loads. A very broad overview of the modeling approach is provided here.

1. The watershed is divided into 94 segments based on natural topography, areas with similar characteristics, and the location of monitoring stations used for calibration. Segments generally become smaller closer to the bay.
2. A land use database available for the entire watershed is used to assign land use to a number of detailed categories within the model, including various agricultural land practices, forested lands, and urban coverage.
3. Pollutant loadings are determined using a variety of routines, including empirical procedures and mechanistic nutrient cycling and export procedures.
4. Point source and septic loadings are included in the model.
5. The model is run on an hourly timestep, and is calibrated to the 1984-1995 time period for both runoff and water quality. An approach has been developed to address land-use change, and therefore pollutant loading change, over the duration of the calibration period.
6. The results are reported by basin and on a 10-year average load basis.

7. An updated version of the model is currently under construction which will have significantly more segments to allow for greater calibration; will cover a longer simulation period (through 2002); and will include more land cover types.

4.4.3 Summary of Agency Approaches

The agencies reported a range of approaches to calculating pollutant load reductions. These varied from not performing any calculations at all to including estimates of BMP performance within a sophisticated watershed model.

4.4.3.1 Simplified Approaches

The majority of agencies interviewed stated that they do not apply any estimates of BMP performance to determine pollutant load reductions. Most said they would like to use this approach, but cited the lack of adequate BMP performance data as a significant problem. Many agencies did not use estimates of BMP effectiveness but said they relied instead on monitoring data to establish the magnitude of load reductions.

Some agencies use simple surrogates rather than direct estimates. For example, the Maine Department of Environmental Protection (Maine DEP) determined that they needed a 65% reduction in fecal coliform within a given watershed. They concluded that they had achieved this reduction when 65% of the septic systems were upgraded and 65% of the feedlot operations within the basin had installed BMPs. No actual calculation was performed to determine exactly how much of a load reduction would be achieved by implementing these measures; monitoring was used instead to determine water quality improvement.

4.4.3.2 Application of Numeric BMP Performance Estimates

Three agencies reported using BMP performance estimates to pollutant load reductions. Florida has applied standard BMP performance estimates from the EPA as well as values from recent research, New York has utilized standard BMP performance estimates available in GWLF, and the Chesapeake Bay Program has established performance estimates for a group of about 40 BMPs that are used in their watershed model. Of these, the Chesapeake Bay Program appears to be the most sophisticated approach, and perhaps most comparable to the proposed Tahoe basin TMDL program.

The Chesapeake Bay Program has invested a significant amount of effort into defining and incorporating BMP effectiveness into their TMDL program. BMP performance estimates are established by subcommittees referred to as ‘tributary strategy workgroups’; they have defined approximately 40 BMP numeric performance estimates to date. The Chesapeake Bay Program watershed model is updated annually with revised land use and BMP installation data provided by the various partners. This information is provided by county, aggregated by watershed segment and finally entered into the model. In the case of nutrients, the watershed model calculates reductions from three sources: land use conversions (i.e. conventional tillage to conservation tillage), construction of specific BMPs, and implementation of nutrient management techniques. Nutrient and sediment reductions are modeled by applying percent reductions to loads from pervious and impervious surfaces on a model segment basis. Changes in loadings can be compared for different land use and BMP scenarios.

5.0 DEVELOPMENT OF APPROACH

This section summarizes the screening of potential methods and provides the rationale for selection of the selected approach for estimating pollutant load reductions.

5.1 Key Objectives

As noted in Section 2, a methodology is needed in Lake Tahoe that:

- Addresses different geographic scales (e.g., regional, project, individual BMP),
- Addresses the effects of both source controls and storm water treatment BMPs,
- Addresses maintenance and monitoring effects,
- Focuses on pollutant of concern for Lake Tahoe (inorganic particulates <20 microns, nitrogen species, phosphorous species),
- Applies to different stages of project development (e.g., conceptual planning, watershed analysis, detailed design), and
- Can be adapted to support the future TMDL implementation system.

Potential methods were evaluated based on their ability to meet the above needs either immediately or in the relatively near future, recognizing that this project can provide only a first step towards some of these needs. The results of Tasks 1 and 2, and further consideration of practical approaches for implementation in Lake Tahoe Basin, were used to guide development of the methodology based on the list of needs.

5.2 Lessons Learned From Interviews

5.2.1 Tahoe Interviews

The most significant topics and themes from the Tahoe interviews that influenced development of the proposed approach are listed below.

1. The methodology should be as quantitative, objective, and consistent as possible to reduce subjectivity in project review and permitting.

2. Although a consistent or standardized methodology is needed, flexibility for the user is also required to account for project-specific conditions. User flexibility should be accompanied by transparency of deviations or variations from the standard in order to facilitate review.

3. A better connection is needed between pollutant load reduction performance and design. The methodology should estimate load generation and reduction for all target pollutants.

4. Pollutant source controls and hydrologic source controls will continue to play a significant role in water quality improvement, and their effects need to be integrated with estimates of treatment performance for major BMPS in order to evaluate overall project effectiveness.

5. Better tools for estimation of the effects of hydrologic source controls are available, but are currently beyond the scope of most projects. A simple method is needed to integrate these techniques into project assessment and design.

6. Maintenance of BMPs is a significant factor in selection and performance, and needs to be incorporated into the methodology.

7. The methodology should account, to the extent feasible, for variations in design (sizing, configuration, setting, etc.) of BMPs that will continue to occur as the result of site and other constraints.

5.2.2 National Interviews

Recommendations from researchers and program personnel were valuable for considering the appropriate level of complexity of methods for estimating pollutant loads. The interviews presented a broad perspective from academics and implementers in this respect. The most significant topics and themes from the national interviews that influenced development of the proposed approach are listed below.

1. Better estimation of pollutant loads is considered possible with continuous hydrologic modeling than with event-based or empirical estimates. Continuous simulation accounts for important processes, and is better able to account for the effects of hydrologic variability on BMP performance with time. The additional complexity in modeling is a disadvantage, but may be worthwhile as the most feasible way to improve pollutant load estimates.

2. In contrast to the trend for more complex representation of hydrologic processes, empirical, land use-based methods may be most practical for estimating water quality concentrations and loads, at least initially. More complex relationships (e.g., build-up/wash-off) were considered difficult to justify for the purpose of estimating long-term effects.

3. Process-based estimates of BMP effectiveness may not be practical. The lack of adequate BMP performance data and a poor understanding of the physical and chemical processes in treatment BMPs are significant constraints. The most feasible initial approach for estimation of treatment effectiveness for most constituents may be empirical.

4. The adaptive management approach based on monitoring and new information is critical to program implementation. The methodology should help to establish monitoring and research needs, and should be flexible enough to incorporate future refinements.

5.3 Screening of Potential Methods

Quantitative estimates of pollutant loads or load reductions involve multiple processes and elements - precipitation and runoff; pollutant load generation from land uses and specific sources; reduction of loads in distributed pollutant source and hydrologic controls; and treatment of flows in major BMPs are all complex processes. The integration of these elements into a methodology for estimating pollutant loads and load reductions can therefore quickly reach overwhelming levels of complexity. The project scope of work envisioned identification of multiple methods from the Lake Tahoe and the national surveys that could be evaluated individually and in combination. As work proceeded, it became clear that viable methods were few, and while different methods were in use, most shared similar technical basis and limitations. The primary differences between methods involved levels of complexity in considering various physical and chemical processes; and in computational differences between modeling, empirical estimates, and statistical approaches.

The screening of potential methods therefore considered a range of computational schemes with varying levels of complexity and input data requirements. The computational approaches were evaluated in terms of the input and calibration data available to support them, the reliability or improved accuracy of more complex versus simpler schemes, and the ability of the end users to practically implement them.

While absolute accuracy was not expected at the inception of the project, reasonable accuracy in estimating pre- and post-project pollutant loads is needed. It is clear that this objective presents significant challenges, and needs to be considered in the context of adaptive management. In order to evaluate potential approaches with varying levels of complexity, the methodology was organized into three interdependent elements:

1. Hydrology
2. Pollutant Load Generation
3. Storm Water Treatment

The hydrology element focuses on estimating storm water runoff and the reductions in storm water runoff due to hydrologic source controls.

The pollutant load generation element focuses on estimating the total pollutant load from a drainage catchment based on the specified characteristics. Additionally, the pollutant load generation element focuses on estimating pollutant load reductions due to pollutant source control implementation. This reflects the distributed nature of many source controls, which influences the amount of pollutants entering major flow streams.

The storm water treatment element focuses on methods to estimate the portion of the pollutant load that can be removed by significant storm water treatment BMPs. Note that hydrologic source controls and pollutant source controls, although parts of other elements, also contribute substantially to overall load reduction.

The reader may recognize that the major elements are similar to the components addressed in the Preferred Design Approach (CTC 2002). This organization structure was selected because it provides a logical progression of the physical processes involved in pollutant load delivery. The remainder of this document and the selected approach are predominantly organized and described using these three main elements.

5.3.1 Hydrology Element

A variety of hydrologic methods are currently in use in the Lake Tahoe Basin (see Section 2), but most are focused on computation of flows for the purpose of sizing conveyance or storage facilities, and not specifically as the basis for computation of pollutant loads.

Table 5.1 shows three levels of hydrologic computations considered as the basis for estimating pollutant load reductions. Level 1 includes empirical and statistical methods that do not directly involve time dependent models of watershed processes. Level 2 includes methods that generate event hydrographs, usually based on lumped watershed and routing parameters. Level 3 includes continuous simulation methods, and compared to other methods has more emphasis on distributed watershed processes, including hydraulic flow routing, and longer term simulations. Within all three levels, the relative complexity and basis in physical processes vary, but the progression from Level 1 through Level 3 generally coincides with increasing complexity, data requirements, and number of calibration parameters.

Table 5.1 - Levels of Hydrologic Modeling Complexity

	Level 1: Empirical / Statistical	**Level 2: Event Hydrograph**	**Level 3: Continuous, Process-Based**
Time Step	daily to yearly	minutes to hourly	minutes to daily
Runoff Metrics	Volume per unit time or flow vs. probability	Flow rate vs. time, short term	Flow rate vs. time, long term
Hydrologic / Hydraulic Processes	Interception, depression storage, infiltration losses	Overland flow, depression storage, channel flow, detention storage, infiltration losses	Overland flow, depression storage, snowmelt, soil moisture storage, channel flow, detention storage, infiltration, evapotranspiration
Example Methods/Models	Rational Method, Simple Method, Flow Duration	TR-55, TR-20, HEC-1, HEC-HMS, SWMM*, HSPF* *if run for event period	SWMM, HSPF, STORM

In the Tahoe Basin, where a large fraction of the total precipitation occurs as snow and drainage systems frequently include pervious elements, estimates of long-term runoff volume (and therefore pollutant loads) are sensitive to analysis methods used for small runoff events and routing of low flows. Based on researcher and program staff recommendations, continuous hydrologic simulations are believed to provide substantially better estimates in this regard than event-based estimates. Compared to empirical estimates, they also provide more information (a long-term time series of flows) for use in estimating BMP effectiveness. Although process-based estimates of BMP performance may not be practical at this time for all constituents, use of a more process-based approach for hydrology will allow this type of refinement in the future. If empirical estimates were used for hydrology, it is difficult to support the accuracy of more process-based approaches for pollutant load generation or load reduction. In addition, the watershed modeling currently in progress for Phase 1 of the TMDL uses a continuous simulation approach. Selection of the same approach for the methodology developed in this project is a step towards consistency between the two TMDL-related efforts. Based on this reasoning, incorporation of continuous hydrologic simulation methods (Level 3 in Table 5.1) was selected as the preferred approach for the hydrology element of the methodology.

The continuous process-based methods shown in Level 3 of Table 5.1 involve fairly complex hydrologic modeling with numerous input data and calibration requirements. The application of these methods is not common in the Tahoe Basin, and the relative complexity may conflict with the objective of the making the methodology practical for Lake Tahoe Basin implementers.

For this reason, the screening process involved consideration of a simplified application of continuous hydrologic simulation through a user-interface. This approach was tested by considering the sensitivity of results to various input variables, and the ability of a simplified interface to provide reasonable results on which to base pollutant load generation and storm water treatment computations.

5.3.2 Pollutant Load Generation Element

In most methods, pollutant loads are generated by integration of the product of flow and concentrations over time. Table 5.2 lists the methods considered, increasing in complexity from Level 1 to Level 3. While process-based models are attractive from a scientific perspective, interviews with researchers confirmed that this approach is still on the leading edge of current research, and practical implementation is limited by available data and understanding of unit processes. In the majority of cases, other programs have linked load generation to land use with empirical estimates. The watershed model for Phase 1 of the TMDL includes such an empirical approach, but also includes a process-based approach for sediment in LSPC. However, the project team felt that at the desired project scale, a process-based approach would likely lead to a very high level of complexity to model load generation from various surfaces.

Table 5.2 - Load Generation Methods Associated with Hydrologic Modeling

	Level 1: Empirical / Statistical	**Level 2: Event Hydrograph**	**Level 3: Continuous, Process-Based**
Time Step	daily to yearly	minutes to hourly	minutes to daily
Typical Associated Water Quality Methods	Annual Export, Simple Method, Concentration vs. Q integration, USLE, MUSLE, RUSLE	MUSLE, SWMM and HSPF Routines	Build-Up/Wash-Off, GWLF, RUNQUAL, LSPC, SLAMM, P8, SITEMAP, HSPF, SWMM

The selected approach was therefore to link results from simplified continuous simulation for hydrology with empirical estimates of concentrations characteristic of particular land uses. This approach is consistent with the watershed model, except that it does not include process-based estimates for erosion or sediment transport.

In addition to distributed sources that can be characterized by land use, there is a need to estimate loads from specific sources that are not represented by Tahoe Basin water quality data for particular land uses. These loads might be quite large if associated with significant problems. For example, an eroding gully contributes disproportionately high loads per unit area. For this purpose, the approach selected was to combine empirical estimates based on land use with estimates of loads for specific sources. The latter might be generated directly as a load, or in combination with hydrologic estimates.

In addition to estimating pollutant loads generated from an existing condition, a method is needed to estimate the pollutant load generated after implementation of pollutant source controls. Due to the distributed nature of many pollutant source controls, a practical approach is to estimate their effects as part of the load generation element. Sufficient data on effectiveness of pollutant source controls, both in Tahoe and elsewhere, was not found to be readily available for use in directly estimating loads or load reductions. However, the PAC agreed that inclusion of pollutant source controls is an important factor in the overall performance of a storm water management system. Therefore, the method selected subjectively uses a statistical approach based on the available data for Lake Tahoe by land use.

The overall approach developed for pollutant load generation uses a combination of statistical and empirical methods noted in Table 5.2. Relatively simple methods were selected due to low confidence that more complex methods would yield improved results, and because it is consistent with at least a portion of the methods being used in the watershed model for Phase 1.

5.3.3 Storm Water Treatment Element

Similar constraints apply to storm water treatment estimates as to load generation estimates. Priority pollutants for the Lake Tahoe TMDL are fine sediment and biologically available nutrients. Very little monitoring data is available on particle size distributions in runoff, fractionation of nutrient loads, effectiveness of BMPs on the fine sediment and dissolved nutrient fractions, and the variability in effectiveness under different hydraulic conditions (e.g., residence time).

Table 5.3 illustrates the potential types of methods evaluated for storm water treatment associated with the three levels of hydrologic modeling complexity. Progression from Level 1 through Level 3 generally coincides with increasing ability to incorporate physically-based estimates of load reductions, but also requires an increasing level of complexity and number of calibration parameters.

Table 5.3 - Load Reduction Methods Associated Hydrologic Modeling Complexity

BMP Type	Treatment Mechanism	Level 1	Level 2	Level 3
Source Controls	Volume Capture - Interception / Depression Storage	E	E	E,P
	Volume Loss - Imperviousness Reduction / Disconnection	E	E,P	P
	Volume Loss - Imperviousness Disconnection		P	P
	Quality Improvement - Maintenance Activities	E	E	E,P
	Hydro-modification Controls		P	P
	Quality Improvement - Land Use Activities	E	E	E
Storm Water Treatment BMPs	Volume Capture - Detention Storage / Flow Rate Non-Exceedance	E	P	P
	Volume Loss - Infiltration / Evapotranspiration	E	P	P
	Hydraulic Retention Time		P	P
	Clogging	E		E,P
	Pollutant Removal	E	E,P	E,P
	Subsurface Transport – Interflow			P
	Hydro-modification Controls		P	P
Treatment Trains	Subcatchment Connections	P	P	P
	Conveyance Connections		P	P

E = Empirically Based P = Physically Based

Although physically-based estimates are ultimately desirable, only one storm water treatment process was identified that the project team had confidence could be well represented by physically based computations. Particle settling theory provides a means to estimate fine sediment removal in some treatment BMPs based on time variant hydraulic conditions. This approach should result in improved estimates for fine sediment removal over purely empirical estimates, although the theoretical basis still has some limitations in many BMP types. For example, particle settling theory applies to gravitational processes but does not account for capture of fine sediment by vegetation or the effects vegetation may have on decreases in turbulent flow.

For constituents other than fine sediment, the project team felt that physical and chemical processes in BMPs are not well enough understood at present to warrant development of a physically-based approach. The selected approach for development of the methodology therefore combines physically-based fine sediment removal estimates and empirical/statistical estimates for typical effluent concentrations of other target pollutants. In both cases, continuous simulation hydrologic results can be used to estimate the volume of storm water runoff captured at the design water quality volumes and flow rates and to estimate volume losses in the BMP. For fine sediment removal calculations the hydrologic results can also be used to calculate hydraulic conditions to estimate sediment removal efficiency from settling theory.

Achievable effluent quality was selected as a preferred approach over an estimated percent removal approach, which is more adaptable to treatment train calculations where multiple percent removal calculations in series may lead to erroneous results. The effluent quality approach was also considered more reasonable where influent quality might be affected by source controls.

5.4 Scale and Compatibility Considerations

In order to address TMDL needs to track pollutant load reductions and provide credits towards allocations, a methodology is needed to estimate potential load reductions at a finer resolution (smaller scale) than the Phase I watershed model. The scope of work for this project noted that a methodology is ultimately needed for application at the individual BMP, project, and regional scales. The screening of potential methods focused most heavily on the project scale, based on perceived needs from the Lake Tahoe interviews in Task 1. The approach selected was to develop a methodology that is applicable to catchments on the order of 5 to 100 acres in size, as this is the scale at which most storm water quality improvements in the Tahoe Basin are designed. Development of modifications to the methodology to address a larger range of scales was deferred with the concurrence of the PAC so that project resources could be focused on the scale believed most applicable to projects.

Application of methods to estimate pollutant load reductions at a project scale may also be used in the TMDL program to set interim milestones (e.g. 5-year objectives) in particular areas of the Tahoe Basin. This application would recognize that a methodology that accounts for individual project effects may be a more effective tool for this purpose than the watershed model, which is more applicable at a larger regional or basin-wide scale.

A second consideration in development of the methodology is compatibility with the watershed model. A few levels of compatibility or "linkage" between the watershed model and the methodology developed here can be considered, such as:

1) application of consistent data sets;
2) application of consistent or similar algorithms for load computations;
3) translation or scaling of results from one method/model to another; and
4) direct output-input linkage for results from one method/model to another.

Initially, consideration was given in this project to developing a methodology that could directly link to the watershed model. This would have both the computational algorithms and input-output variables and formats to be directly transferable between scales. The PAC felt that this might unduly constrain development of a methodology designed to be applicable at finer resolution. In addition, it would likely have required changes in the watershed model to represent the project-scale features. For this reason, the approach taken in this project was to consider the general approach taken by the watershed model effort (as noted in several locations above) and use consistent data sets (e.g., water quality characteristics for land uses and meteorological input data). However, direct compatibility or linkage of input and output was not used as a significant screening criterion.

It is anticipated that further development of the methodology and its relationship to the watershed model (and perhaps further development of the watershed model) will be needed to further address this topic if higher levels of linkage are considered desirable in the future.

However, various options may be explored for application of each tool in the TMDL program, and compatibility at a program level may be feasible without the need for direct linkage.

5.5 Summary of Screening Results

The following list summarizes decisions on methods and approach agreed upon by the PAC during the screening process.

- The pollutant load reduction methodology will focus on pollutant of concern for Lake Tahoe in surface water generated in urbanized areas and subject to potential removal by storm water treatment BMPs.
- Pollutant of concern will be quantified, including total and fine sediment (less than 20 microns), total and dissolved nitrogen, and total and dissolved phosphorus.
- The overall approach is organized into three main elements: 1) Hydrology, 2) Pollutant Load Generation, and 3) Storm Water Treatment.
- The hydrology element will estimate runoff using continuous hydrologic simulation.
- Due to the complexity of continuous hydrologic simulation, a tool will be developed to lessen the complexity and data requirements of the hydrologic estimation, making the methodology more practical for application by implementers.
- Continuous hydrologic simulation will account for reduction in runoff volumes from implementation of hydrologic source controls.
- Pollutant load generation will be based primarily on characteristic event mean concentrations (EMCs) for various land use categories, but will include alternative methods, referred to as specific sources, for pollutants generated that can be considered independent of a land use category or land use condition.
- Pollutant source control implementation will be accounted for in the pollutant load generation element.
- Pollutant source controls include maintenance practices, drainage improvements, stabilization activities (e.g. revegetation and soil restoration), and road sanding management.
- Storm water treatment will primarily use empirically-derived performance data combined with some physically-based simulation for fine sediment removal. Empirical performance data will use median achievable BMP effluent quality rather than percent removals.
- Storm water treatment BMPs represented will include common facilities and designs currently implemented in the Tahoe Basin. The methodology will include flexibility to add additional BMPs over time.
- The methodology will allow for the inclusion of new data related to pollutant load reduction within an adaptive management framework.

6.0 DESCRIPTION OF SELECTED APPROACH

An overview of the selected approach is presented here, and a detailed description of the computation methods is provided in Section 7.

Figure 6.1 conceptually illustrates the three major elements to the methodology: 1) hydrology and hydrologic source controls, 2) pollutant load generation and pollutant source controls, and 3) storm water treatment. User input is required for each element, and the results of each are used in subsequent elements. Pollutant load generation is estimated based on an analysis of hydrologic characteristics, watershed characteristics and land uses that affect pollutant sources and delivery. Storm water treatment represents major treatment BMPs and is based on design parameters, inflowing loads, and hydrologic characteristics. The computed pollutant load represents a combination of hydrologic source controls, pollutant source controls, and storm water treatment.

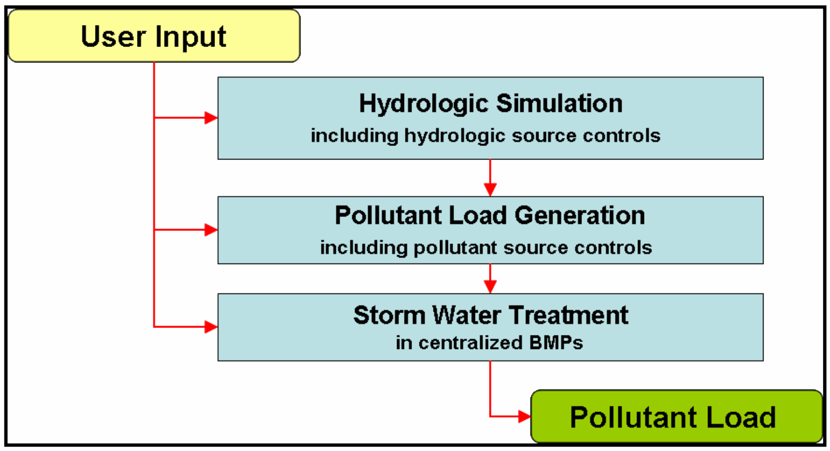


Figure 6.1 - Conceptual Methodology Diagram

6.1 Hydrology and Hydrologic Source Controls

Computation of hydrologic characteristics for pollutant load generation and storm water treatment are based on long-term simulations to represent the effects of natural hydrologic variability on pollutant loads. This requires use of a continuous simulation model and a long-term meteorological data set.

A number of continuous simulation models are in use for storm water computations. For incorporation into the methodology, the U.S. EPA Storm Water Management Model (SWMM) was selected as the hydrologic engine for continuous simulation. Reasons for selection of SWMM include:

1. SWMM, although not widely used in Tahoe, is reasonably familiar to the Tahoe engineering community relative to other continuous simulation models.

2. SWMM has some advantages relative to other models for application in urban environments (impervious area routing, hydraulics, BMP features, etc.).

3. SWMM is publicly available and professionally accepted.

4. SWMM simulates snowmelt hydrology.

The continuous simulation in SWMM uses the synthetic MM5 data set as the meteorological input. The MM5 framework is a fifth generation regional atmospheric model developed jointly by the National Center for Atmospheric Research (NCAR) and Pennsylvania State University, and is particularly well-suited for steep mountainous terrains like the Tahoe Basin (Anderson et al. 2004). The initial development of a Tahoe Basin MM5 data set was performed by a team from the Hydrologic Research Laboratory at the University of California Davis led by Dr. M. Levent Kavvas (Anderson et al. 2004). The MM5 approach was selected for use in the methodology developed in this project because a future version of the MM5 data set will be the meteorological tool used for the TMDL, including the watershed model. The current MM5 data set needs refinement and recalibration; this task is recognized as a top priority for future work implemented by the TMDL program.

The MM5 data set significantly simplifies meteorological data entry needs while providing project area specific meteorological data. The MM5 data set provides a long-term meteorological record representing variable patterns of precipitation based on location and elevation within the Tahoe Basin. The MM5 data set includes temperature data as a means of estimating snowfall and snowmelt. The current MM5 data set recommended for use in the methodology consists of 142 sets of 40-year synthetic meteorological data for the Tahoe Basin. Each data set is associated with a 3x3 kilometer grid cell, as shown in Figure 6.2.

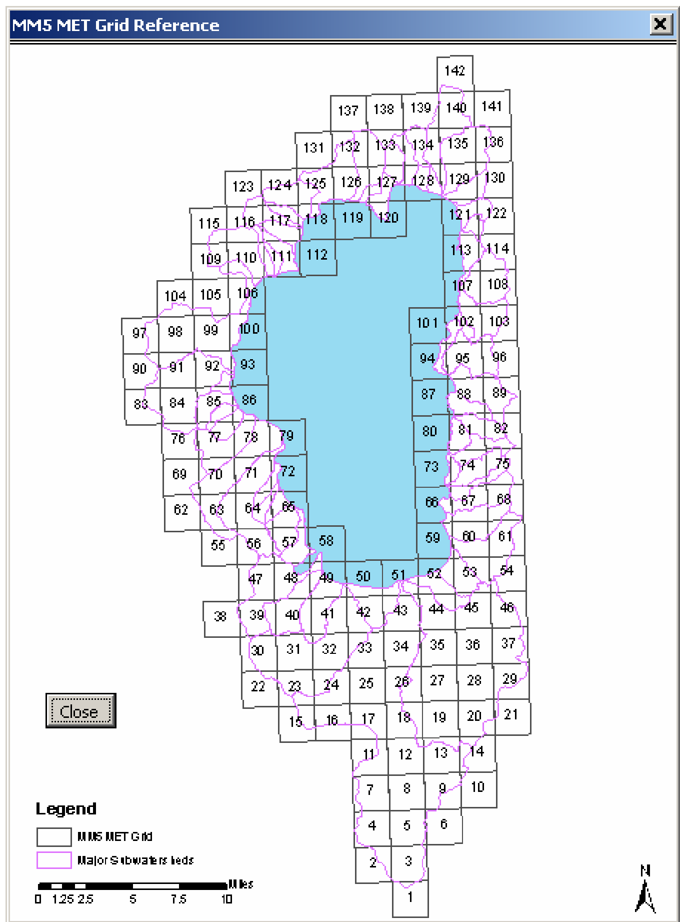


Figure 6.2 - MM5 Grid

The hydrologic methods in the methodology are applicable to pre- and post-project conditions. Effects of hydrologic source control implementation are estimated by changing input parameters for impervious/pervious area, impervious connectivity, soils information, vegetation information, and the infiltration characteristics. In addition to simulating the runoff characteristics of a project area, the methodology allows for input of design criteria for sizing storm water treatment BMPs and for specifying the rates at which storm water treatment BMPs will drain. The design criteria are used during the continuous hydrologic simulation to determine the treated runoff volume and bypassed runoff volume for each treatment BMP.

The average annual runoff volume from the continuous simulation is used by the pollutant load generation element to determine average annual pollutant loads generated.

6.2 Pollutant Load Generation and Pollutant Source Controls

The methodology employs two techniques to estimate pollutant load generation: 1) spatially distributed source accounting (land use based pollutant loading), and 2) specific source accounting (e.g., gully erosion, eroding disturbed areas, road sand). Figure 6.3 displays a simplified flow chart of the pollutant load generation methodology. Spatially distributed source accounting estimates pollutant load generation using the simulated hydrology and land use based event mean concentrations (EMCs). The EMCs used in the methodology were developed from Tahoe Basin monitoring data as part of the Lake Tahoe TMDL Program and are used in both the watershed model and this methodology. The EMCs include land use based estimates of total suspended sediment (TSS), fine sediment (<20 um) as a percentage to TSS, total and dissolved nitrogen, and total and dissolved phosphorus.

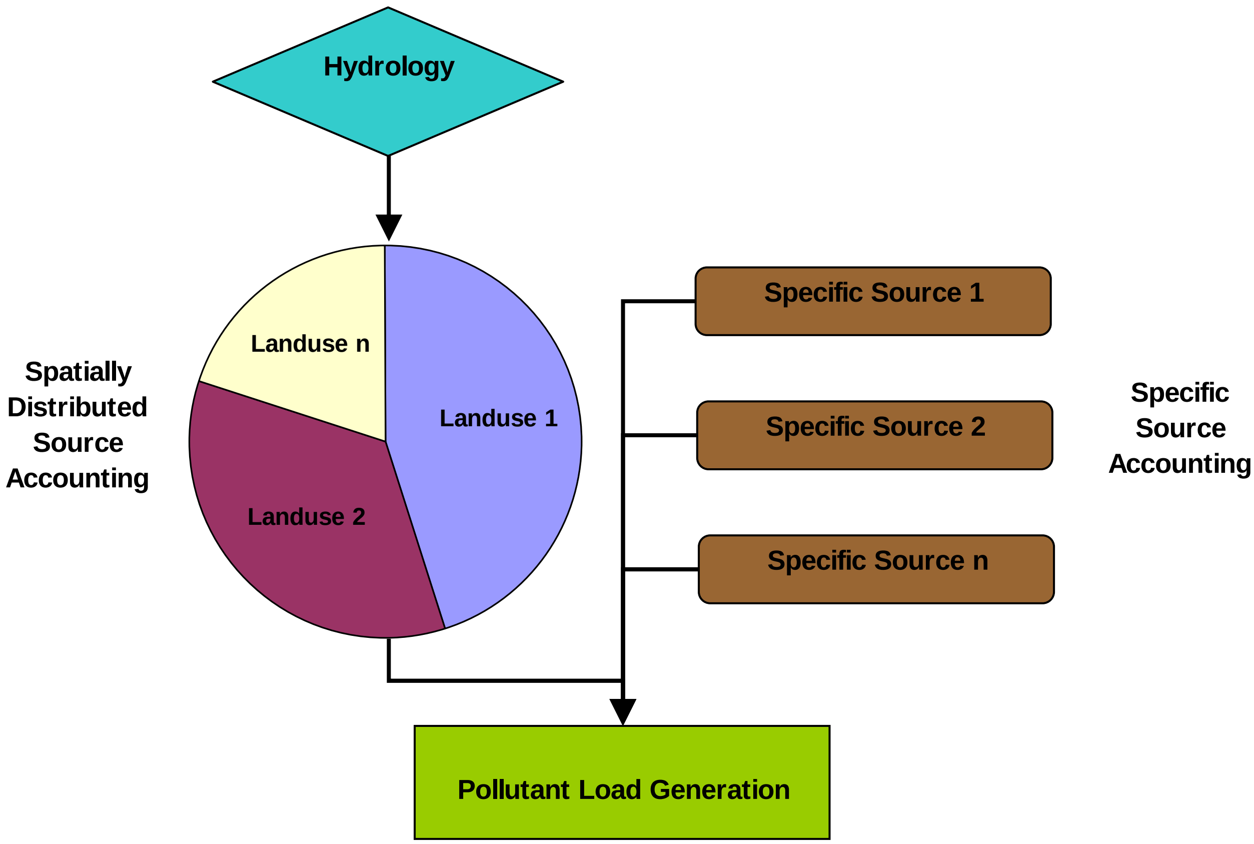


Figure 6.3 - Simplified Pollutant Load Generation Methodology

Specific source accounting estimates pollutant load generation for sources that are generally not associated with a land use, (e.g., road sand, gullies, drainage system degradation, etc). Specific source accounting estimates pollutant load generation by summing the relative yield of pollutants from the defined specific source on an average annual basis (e.g., average annual road sanding on a specified application area, average annual gully sediment yield based on gully advancement, etc.). Specific source accounting requires input data that is unique to the specific source. For example, an estimation of road sand application requires an average annual application rate, the spatial area of application, and the average annual recovery rate due to street sweeping and BMP maintenance.

The two techniques (spatially distributed source accounting and specific source accounting) are used in combination to provide a means to estimate total pollutant load generation for project area conditions. The spatially distributed accounting technique represents loads generated from particular land uses with a single EMC for each pollutant of concern. Therefore, the methodology considers the EMC representation to reflect "typical" conditions. To provide flexibility in pollutant load generation estimates for project areas that deviate from the typical condition, the specific source techniques can be used to represent project areas that are yielding higher pollutant loads than typical conditions because of specific sources.

The pollutant load generation methodology is applicable to pre- and post-project conditions. The effects of source control implementation on pollutant load generation may be estimated by changing input parameters. The spatially distributed source accounting technique represents source control implementation by adjusting the median EMCs for a land use. The specific source accounting technique represents source control implementation as a subtraction in the pollutant load generated for that specific source relative to existing conditions.

6.3 Storm Water Treatment

The reduction in pollutant load achieved by a storm water treatment BMP depends on the portion of the runoff treated and the extent of treatment achieved. The methodology uses a combination of empirically-derived and physically-based methods to represent the range of BMP performance.

Standard design parameters are required for a selected list of storm water treatment BMPs (e.g., wet and dry basins, wetland treatments, bioswales, infiltration galleries, and filtration systems). Examples of standard design parameters include hydraulic capacity and infiltration rates. These parameters are used to estimate the runoff capture ratio and bypass ratio. Performance of volume-based BMPs for fine sediment uses a unit process approach (settling theory based on hydraulic conditions), while performance for nutrients is estimated using empirical data for achievable effluent quality. Performance of flow-based BMPs for all pollutant of concern is estimated using empirical data for achievable effluent quality.

Figure 6.4 illustrates conceptually the pollutant load reduction associated with a storm water treatment BMP. The influent load to BMP 1 is input from the pollutant load generation element. To estimate pollutant load reduction, the hydrology simulation determines the runoff capture volume and bypass volume based on the user-specified water quality design volume or flow rate, and drawdown characteristics for BMP 1. The methodology assumes that the runoff capture volume receives achievable treatment from BMP 1, based on the achievable effluent quality data, while the bypass volume is routed around BMP 1 and thus receives no treatment. This method is a simplifying assumption, recognizing that it does not exactly represent physically bypassed flow in many BMP designs.

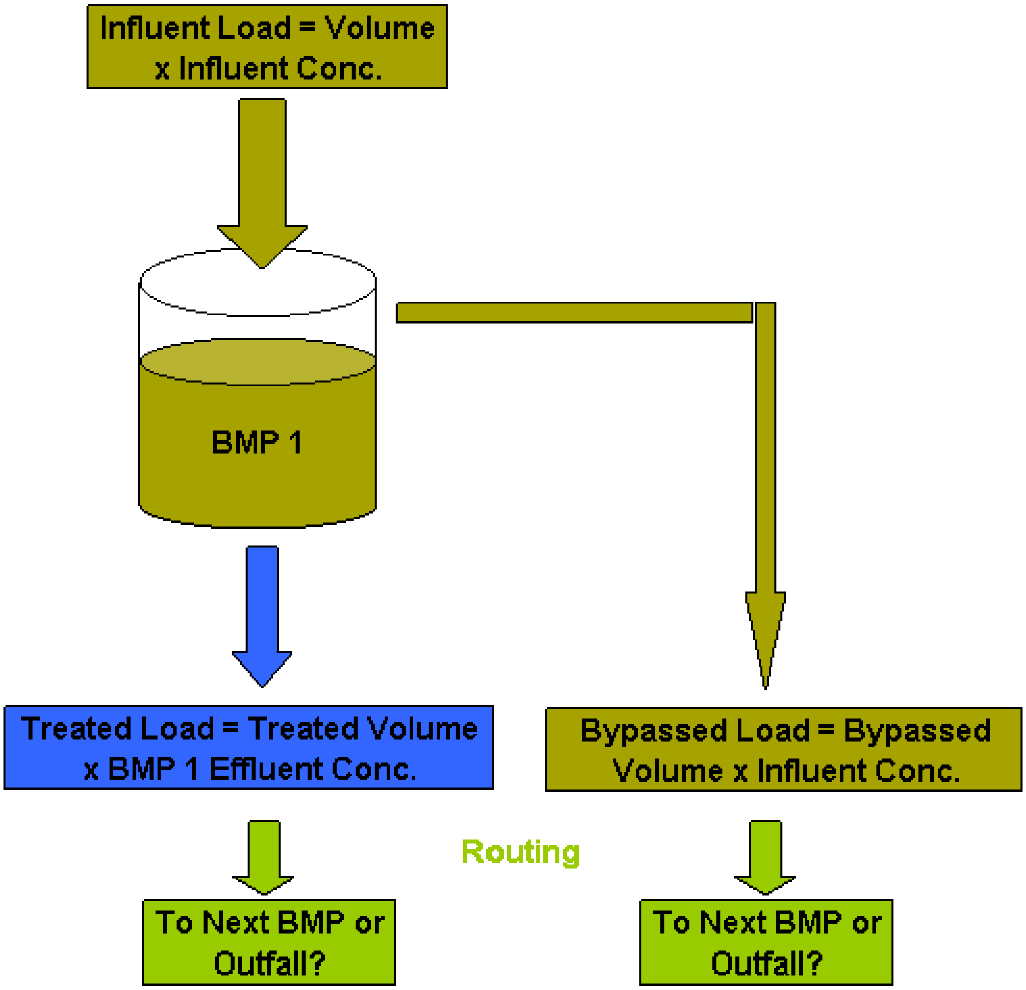


Figure 6.4 - Conceptual BMP Routing Diagram

As shown in Figure 6.4, after runoff has either been routed through or around BMP 1, the total pollutant load remaining is equal to the summation of the treated load and the bypassed load. The treated load is equal to the runoff capture volume of BMP 1 times the achievable effluent quality of BMP 1. The bypassed load is equal to the bypass volume times the influent concentration, which in this example is the initial concentration.

Both the treated load and bypassed load may be routed to either the outfall or a downstream BMP. If either the treated load, bypassed load, or both are routed to a downstream BMP the process described above and depicted in Figure 6.4 is repeated. Up to three storm water treatment BMPs may be simulated in sequence at the end of a drainage catchment, either in parallel or in series.

6.4 Pollutant Load Reduction

The three major elements of the methodology – hydrology, pollutant load generation, and storm water treatment – are described separately in this report but the elements are inherently interdependent for calculation of pollutant load reduction. Modifications to input assumptions and data for any of the three elements may increase or decrease pollutant loading dependent upon the relative change in hydrology or water quality. All three elements may be used to estimate pollutant load reduction with each element designed to represent certain water quality functions and BMPs. For example, the hydrology element can account for the load reduction associated with private BMP implementation by accounting for decreased directly connected impervious area. The pollutant load generation element can account for the load reduction associated with pollutant source control implementation such as increased street sweeping or revegetation and soil restoration of disturbed areas. The storm water treatment element can account for the pollutant load reduction associated with centralized treatment BMPs such as detention basins. Table 6.1 provides examples of BMPs represented in the methodology and the associated element(s) appropriate for accounting for the pollutant load reduction attributed to a particular BMP. The table entries indicate how the calculations are performed to determine effects on pollutant loads.

Table 6.1 - BMP Representation and Associated Element

	Element		
BMP	**Hydrology**	**Pollutant Load Generation**	**Storm Water Treatment**
Private BMP Implementation	Effect on directly connected impervious	N/A	N/A
Removal or Disconnect Impervious Area	Effect on directly connected impervious	N/A	N/A
Pervious Pavement	Effect on directly connected impervious	N/A	N/A
Curb and Gutter	Effect on directly connected impervious	Distributed source control accounting	N/A
Vegetated Ditches	Effect on directly connected impervious	Distributed source control accounting	N/A
Rock Lined Ditches	Effect on directly connected impervious	Distributed source control accounting	N/A
Revegetation	Evapotranspiration and interception	Specific Source Accounting	N/A
Soil Restoration	Effect on infiltration rates	Specific Source Accounting	N/A
Land Use Change	Effect on directly connected impervious	Distributed source control accounting	N/A
Storm Drain	Effect on directly connected impervious	Distributed source control accounting	N/A
Sediment Traps	N/A	Distributed source control accounting	N/A
BMP Maintenance	N/A	Distributed source control accounting	N/A
Street Sweeping	N/A	Specific Source Accounting	N/A
Gully Stabilization	N/A	Specific Source Accounting	N/A
Retaining Structure	N/A	Specific Source Accounting	N/A
Rock Slope Protection	N/A	Specific Source Accounting	N/A

	Element		
BMP	**Hydrology**	**Pollutant Load Generation**	**Storm Water Treatment**
Detention Basin	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit; Settling of fine particles
Wet Pond	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit; Settling of Fine Particles
Media Filter	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit
Wetland Basin or Channel	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit; Settling of Fine Particles
Hydrodynamic Device	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit
Infiltration Swale/Strip	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit
Centralized BMP - User Defined	Treated volume vs. bypassed volume	N/A	Median achievable effluent limit; Settling of Fine Particles

6.5 Target Applications of the Methodology

The focus of the pollutant load reduction methodology is on storm water runoff within developed areas of the Lake Tahoe Basin. Consequently, the developed methodology is applicable to urban runoff processes at the scale of typical water quality improvement projects – drainage catchments on the order of 5 to 100 acres in size. In its current form, the methodology is less applicable to smaller scale analysis (e.g., individual single family residences, small commercial lots, etc.) and larger scale planning projects (e.g., watersheds or regions), but could eventually be modified for these purposes. The concepts and computations focus on the urban processes of pollutant load generation, including the strategies frequently applied to mitigate pollutant loading from the urban environment.

Pollutant delivery and transport processes in runoff from forested lands, and from other sources such as aerial deposition or stream channel erosion, are recognized as significant pollutant loading processes to Lake Tahoe, but are not addressed within this methodology. It is the goal of the TMDL program to develop similar methodologies to address all significant pollutant sources (e.g., upland erosion, stream erosion, atmospheric deposition) and to track pollutant reductions occurring in all source categories. The methodology described in this report is one component in the development of these technical tools, which will be full implemented after approval of final TMDL in spring of 2009.

In the urban environment, the design of storm water conveyance facilities and water quality improvement facilities are typically combined. The selected approach for the pollutant load reduction methodology uses a continuous simulation of hydrology to evaluate pollutant loading. This approach is preferred because it takes into account the sequence of storms, wet vs. dry years, and the effects of infiltration and evapotranspiration on the water balance. The advantage of continuous simulation from a water quality perspective is that actual or synthetic meteorological data can be used directly without statistical interpretation, and that variations in runoff due to changing antecedent or watershed conditions can be inherently accounted for in the simulation. The continuous record best captures conditions that occur relatively frequently and may account for a substantial fraction of total runoff volume. However, this methodology is not intended to replace conventional frequency-based design for conveyance facilities. These facilities are typically designed to meet specific flood management and public safety criteria (e.g. 100-year event), and the design criteria are based on statistical analysis of relatively rare events.

7.0 METHODOLOGY DETAILS AND THE PLRE-STS

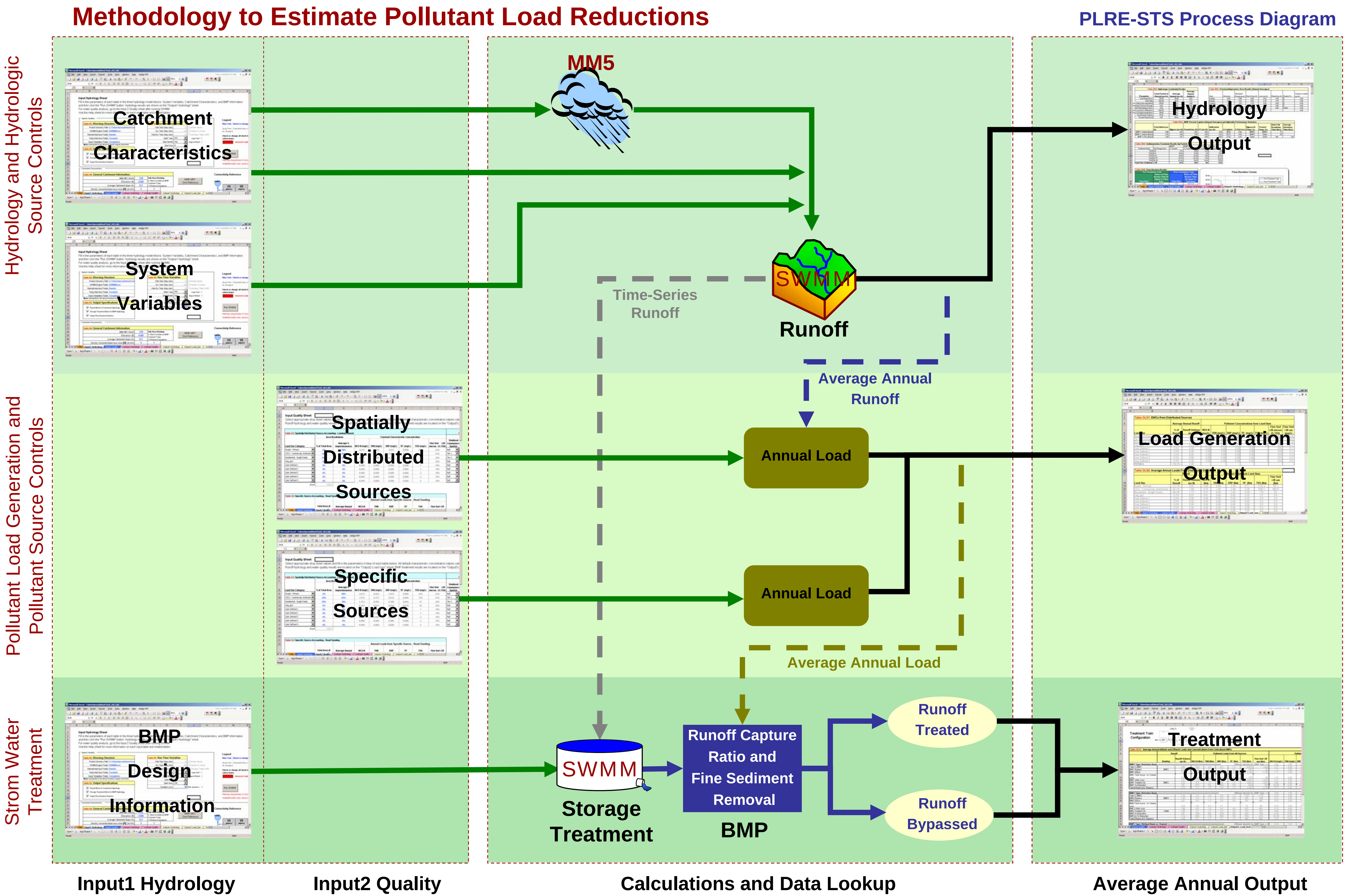
In order to organize and evaluate the applicability of the selected approach, the Project Advisory Committee (PAC) agreed that the conceptual methodology developed in this report would be best illustrated and evaluated using a spreadsheet tool: referred to as the Pollutant Load Reduction Estimator – Spreadsheet for Tahoe Storm Water (PLRE-STS). However, development of a computational tool was not included in the original scope of work. The main work product for this report is the conceptual methodology, and the PLRE-STS should be considered a prototype computational tool used to illustrate and evaluate the conceptual methodology. In the context of this report, "prototype" means that a relatively complete computational tool is ready for initial testing and further development. The completed products of work, defended as a significant advancement in the development of a pollutant load reduction methodology for storm water quality improvement projects in the Lake Tahoe Basin, are the selected approach and conceptual methodology described in this report.

The PLRE-STS is a single Excel file containing multiple worksheets used for data input, internal data lookup, and output summaries linked internally and externally by Excel macros and computer code. Figure 7.1 displays the conceptual Process Diagram for the PLRE-STS. The Process Diagram is organized to display the main input, calculation, and output components of the three elements of the methodology: 1) hydrology and hydrologic source controls, 2) pollutant load generation and pollutant source controls, and 3) storm water treatment. The Process Diagram presents a relatively simplistic summary of the PLRE-STS. To gain a better understanding of the PLRE-STS within the context of the methodology, the reader will likely benefit from frequent referral to Figure 7.1 during the review of this section.

The PLRE-STS accepts user defined inputs for project area characteristics and design criteria and provides output on hydrologic characteristics and pollutant loads. The PLRE-STS allows a continuous hydrologic simulation to run "in the background" based on simplified input parameters, and automatically links this simulation to load reduction computations. The overall design of the PLRE-STS is intended to be practical for application by implementers. Application of the PLRE-STS does not require expertise in hydrologic and water quality calculations but does require some training in hydrology, water quality, and the application of models.

In addition to the automated techniques, the structure of the PLRE-STS was designed for transparency and flexibility. For example, default values are provided in look-up tables for many of the pertinent input parameters for hydrologic and water quality analysis in the Lake Tahoe Basin (e.g. soils data, BMP effluent concentrations, characteristic land use concentrations, etc.). The lookup tables have been designed to allow a user to deviate from the default values if project specific data or professional judgment warrants. This built-in flexibility allows for simple refinements to the methodology in the event that new monitoring data or policy decisions result in a revision to the current data assumptions in the PLRE-STS.

The PLRE-STS computes pollutant loads for user defined conditions – the load reduction attributed to changes between pre-project and post-project conditions must be determined by comparing output for the two conditions. The PLRE-STS estimates pollutant loads at the drainage catchment outlet for total sediment, fine sediment (less than 20 microns), total nitrogen, dissolved nitrogen, total phosphorus, and dissolved phosphorus.


Methodology to Estimate Pollutant Load Reductions
PLRE-STS Process Diagram
Hydrology and Hydrologic Source Controls
Pollutant Load Generation and Pollutant Source Controls
Strom Water Treatment
Catchment Characteristics
System Variables
MM5
SWMM
Runoff
Time-Series Runoff
Hydrology Output
Average Annual Runoff
Spatially Distributed Sources
Specific Sources
Annual Load
Annual Load
Load Generation Output
Average Annual Load
BMP Design Information
SWMM
Storage Treatment
Runoff Capture Ratio and Fine Sediment Removal
BMP
Runoff Treated
Runoff Bypassed
Treatment Output
Input1 Hydrology
Input2 Quality
Calculations and Data Lookup
Average Annual Output

7.1 Hydrology and Hydrologic Source Controls

The hydrologic component of the PLRE-STS utilizes EPA's Storm Water Management Model (SWMM) for simulating rainfall-runoff processes and BMP flow routing. The PLRE-STS provides a simplified and flexible interface to SWMM. The following subsections describe the hydrologic component of the PLRE-STS and the integration of SWMM modeling results into the water quality calculations.

7.1.1 SWMM

The PLRE-STS currently uses a customized version of SWMM4.4h, a description of which can be found at http://ccee.oregonstate.edu/swmm/. SWMM4 utilizes six modules, or blocks, within its main program to simulate different hydrologic and hydraulic regimes, including the Rainfall Block, Temperature Block, Runoff Block, Storage-Treatment Block, Transport Block, and Extran Block. SWMM5, recently developed by the USEPA, is the updated (2004) version of SWMM, which incorporates all of these blocks into one program that is accessed by a relatively simple object-oriented Graphical User Interface (GUI). SWMM4 was chosen over SWMM5 for this project because of differences between the two for simulation of BMP hydraulics and treatment performance. SWMM5 provides for user-specified removal functions, applicable to a representation of storage as a continuous-flow, stirred tank reactor (CFSTR). While several BMPs may be approximated as a CFSTR, plug flow is more applicable for the centralized, end-of-pipe BMPs being simulated by the PLRE-STS (e.g., detention basins, wetlands, swales, etc.). Also, SWMM4 uses discrete particle settling theory for estimating sediment removal, while sedimentation theory is not implemented in SWMM5.

Only two of the six SWMM modules are utilized directly by the PLRE-STS: the Runoff Block and the Storage Treatment Block. These two modules are used to simulate runoff hydrology and detention storage dynamics. Since the primary purpose of the PLRE-STS is to evaluate average water quality conditions with minimal input data requirements, the hydraulic routing capabilities offered by the Extran and Transport Blocks were not utilized. These two modules require detailed storm drain information such as pipe/channel dimensions and invert elevations within a schematic network of the drainage system. Small time steps, which significantly increase the model run-time, are also required in order to solve the complex routing equations and converge on a solution when simulating hydraulics using these modules. The Runoff Block allows simple routing of flows within a catchment and the Storage Treatment allows for routing between BMPs. Because simplified routing was considered sufficient for this version of the load reduction methodology, the Extran and Transport modules were not needed. The SWMM Rainfall Blocks and the Temperature Blocks were used to pre-process the MM5 rainfall and temperature data for the entire Tahoe Basin, but are not used directly by the PLRE-STS. Rather, the pre-processed data files are referenced directly. The following paragraphs provide an overview of the Excel spreadsheet-SWMM interface, the run-time variables, and the modifications that were made to the code of the SWMM engine during this project.

7.1.1.1 Interface Overview

The interface to SWMM is intended to give the user the option to either: 1) input the minimum site-specific information by accepting most or all of the default values or 2) input detailed site-specific information by modifying the default values. Minimum required site-specific information for the hydrologic component is input into the *Input1 Hydrology* sheet of the PLRE-STS, while default values may be modified in the *Lookup1 Hydrology* sheet.

The hydrologic component of the interface has been divided into three input blocks: System Variables, Catchment Characteristics, and BMP Design Information. These three blocks constitute the minimum input data requirements for simulating hydrology using the PLRE-STS. Figures 7.2 through 7.4 are snap shots of these three input blocks within the PLRE-STS. Note that all text in blue, as well as all drop down boxes and check boxes, are available for modification by the user.

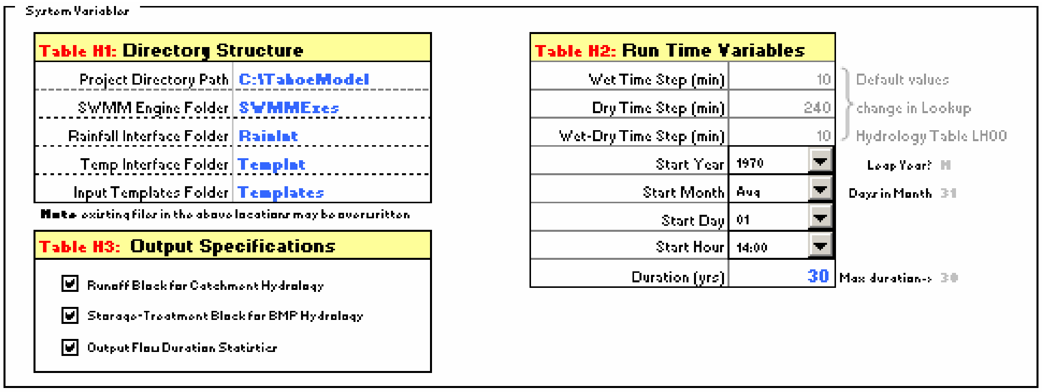


Figure 7.2 - System Variables Input Block

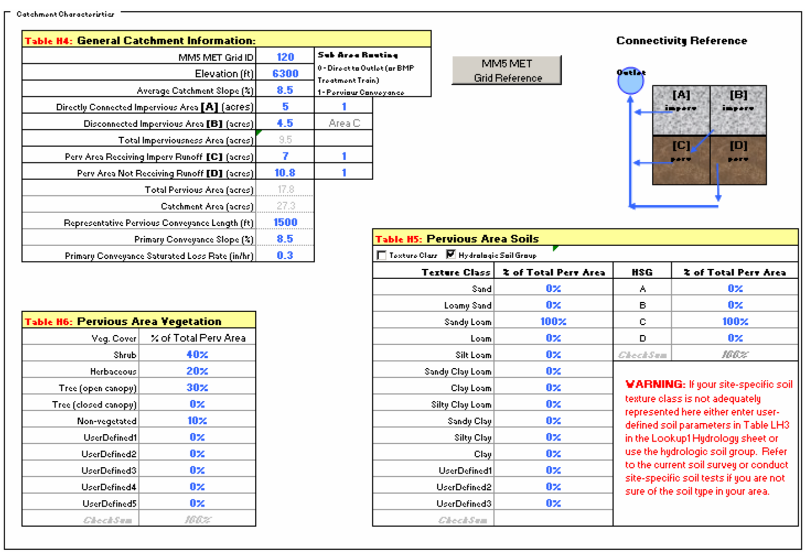


Figure 7.3 - Catchment Characteristics Input Block

BMP Information

Flow-Based BMP Info

Volume-Based BMP Info

Table H7: BMP Routing and Loss Characteristics				
General Data:				
Storage-Treatment Time Step (min)	10	<= Default value change only in Lookup Hydrology Table LH00		
		Upstream to Downstream		
Treatment Train Configuration:	**BMP1**	**BMP2**	**BMP3**	
BMPs Simulated	Yes	No	No	
BMP Type	Detention Basin	Biofilter	Wetland Channel	
BMP Hydraulics	Volume-Based	Flow-Based	Flow-Based	
Bypass flow routed to	Outlet	Outlet	Outlet	
Treated flow routed to	Outlet	Outlet	Outlet	
BMP Loss Rate (in/hr)	0	2	2	Required for flow-based;optional for volume-based
WQ Design Flow Rate, Q_{design} (cfs)	0	1	2	<= (set to zero if not used)
Length to width ratio	2	15	10	<= Must be greater than zero
Additional Parameter Required for Flow-Based BMPs				
Characteristic Footprint Area (sf)	50000	500	10000	<= Effective area for which losses may occur, must be greater than zero
Additional Parameters Required for Volume-Based BMPs				
Water Quality Design Volume (cu-ft)	10000	5000	10000	<= **NOT** including wet pool.
Permanent Wet Pool Volume (cu-ft)	0	0	0	
Permanent Wet Pool Depth (ft)	0	0	0	
WQ Design Depth (live storage) (ft)	4	4	4	
Total Basin Depth (ft)	4	4	4	
BMP Stage-Discharge	Default	Default	Default	For User-Supplied, discharge should be zero up to the top of the wet pool volume and final depth should equal the total basin depth
Brim-Full Draw Down Time (hours)	24	30	24	

MODIFY these tables if the BMP Stage-Discharge drop down select box is switched to "**USER-SUPPLIED**".

Table H8-1: User-Supplied Stage-Discharge for BMP 1

Depth (ft)	Area (ft²)	Outflow (cfs)
0.0	2500	0
0.27	2500	0.05787
0.51	2500	0.05787
0.76	2500	0.05787
1.01	2500	0.05787
1.26	2500	0.05787
1.50	2500	0.05787
1.75	2500	0.05787
2.00	2500	0.05787
2.01	2500	0.11574
2.34	2500	0.11574
2.68	2500	0.11574
3.01	2500	0.11574
3.34	2500	0.11574
3.68	2500	0.11574
4.00	2500	0.11574

Table H8-2: User-Supplied Stage-Discharge for BMP 2

Depth (ft)	Area (ft²)	Outflow (cfs)
0.0	500	0
0.3	500	0
0.5	500	0
0.8	500	0
1.1	500	0
1.3	500	0
1.6	500	0
1.9	500	0
2.1	500	0
2.4	500	0
2.7	500	0
2.9	500	0
3.2	500	0
3.5	500	0
3.7	500	0
4.0	500	0

Table H8-3: User-Supplied Stage-Discharge for BMP 3

Depth (ft)	Area (ft²)	Outflow (cfs)
0.0	1000	0
0.3	1000	0.2
0.5	1000	0.6
0.8	1000	0.8
1.1	1000	1
1.3	1000	1.2
1.6	1000	1.4
1.9	1000	1.6
2.1	1000	1.8
2.4	1000	2
2.7	1000	2.2
2.9	1000	2.4
3.2	1000	2.6
3.5	1000	2.8
3.7	1000	3
4.0	1000	3.2

Figure 7.4 - BMP Design Information Input Block

7.1.1.2 SWMM Control Variables

The System Variables (Figure 7.2) allow the user to specify and/or view the SWMM model directory structure, run-time variables, and output specifications. Additional control variables and configuration parameters are located in the Runoff Block and Storage-Treatment Block template files (located in Templates folder) and the hidden SWMM Input sheet. These primarily include default model parameters that should not be modified in this version of the PLRE-STS. To increase the flexibility of the PLRE-STS in the future, some of these parameters might be allowed to be varied by the user, such as the default area depletion curves for snow melt simulation or the default stage-discharge relationship that is used for volume-based BMPs (see Section 7.1.3.3, Design Characteristics). However, any future efforts to increase the flexibility of the PLRE-STS by allowing changes to default variables should also consider the trade-off with increased complexity of use and input requirements.

The directory structure includes the path to the project directory and the name of all subfolders containing the SWMM engine, the preprocessed rainfall and temperature MM5 interface files, and the input template files for the Runoff and Storage Treatment Blocks. The naming convention of these files should not be changed. Because all of the input data sets have been pre-processed, the current version of the PLRE-STS can only use the MM5 data. All SWMM output files will be stored in the project directory upon execution. If the output folders do not exist, they will be created. Existing SWMM output files will be overwritten if the same MM5 data set is chosen. However, the SWMM output files are primarily used to generate the average annual output tables which are written to the PLRE-STS. Output in the PLRE-STS will not be overwritten if the user saves and renames each simulation when using the PLRE-STS.

The run-time variables include the modeling time steps, start date and time, and simulation duration. It is recommended that the modeling time steps be modified only by an experienced hydrologic modeler. As such, the time steps can only be changed in the *Lookup1 Hydrology* sheet of the PLRE-STS.

The user has to choose to run the Runoff Block to get catchment runoff output, the Storage Treatment Block to get BMP flow routing output, and the flow duration statistics to get flow duration information.

7.1.1.3 Engine Modifications

The FORTRAN source code for SWMM version 4.4h was modified to simulate additional processes and provide additional output not offered by the original engine. One of these modifications included the option to output flow duration statistics from the Runoff Block (i.e. flows *to* the BMP treatment train) and from the Storage Treatment Block (i.e. flows *from* the BMP treatment train). Flow duration statistics provide the hours of flow over the entire simulated period for which various flow rates have been exceeded. While this information is not used for estimating pollutant loading, it can be used to help assess potential hydromodification impacts (or reductions thereof) to receiving streams.

Infiltration-based BMPs are among the most effective for reducing storm water runoff in the Lake Tahoe Basin. However, the original SWMM engine only simulates water losses from BMPs via evaporation. Therefore, the source code was modified to allow the user to specify a constant infiltrative loss rate in storm water BMPs. This loss rate is independent of the depth of water, but is directly dependent on the hydraulic residence time. Therefore, BMPs designed to detain storm water will achieve higher infiltrative losses than BMPs designed for continuous flow-through.

The final modification to the SWMM engine was allowing for the output of average hydraulic residence time (HRT) for each BMP. This output does not directly affect the water quality performance of the BMP since this component of the model is currently empirically-based[1] and there are insufficient data to develop statistical relationships between effluent quality and HRT for all BMPs. Nonetheless, the average HRT for each BMP is made available to the user as an additional check on the adequacy of the size and design of the BMP.

7.1.2 Catchment Characteristics

The required input for simulating long-term runoff from a catchment through the execution of the Runoff Block of SWMM includes the basic information typically required by hydrologic models: total drainage area, imperviousness, slope, soils, and vegetative cover. Some additional information required for the PLRE-STS includes the MM5 Met grid identification number, elevation, impervious and pervious connectivity, and pervious conveyance length and loss rate. The MM5 ID number is used by the PLRE-STS to identify the preprocessed rainfall and temperature data files. Elevation is required by SWMM for the snowmelt calculation (see SWMM Manual for details). Brief discussions of the most sensitive catchment hydrologic parameters and their surrogates are provided below.

7.1.2.1 Impervious/Pervious Area Connectivity

For the purposes of allowing for the simulation of hydrologic source controls, including a representation of private BMP implementation, a catchment is divided into two impervious sub-areas and two pervious sub-areas. One of the impervious sub-areas (Area A) is directly connected to the conveyance system, while the other impervious sub-area (Area B) is directed to a pervious sub-area (Area C) as a means of reducing runoff. Both pervious sub-areas (Areas C and D) are directly connected to the conveyance system. Figure 7.5 illustrates this connectivity concept. By dividing a catchment into these four sub-areas, the disconnection of impervious areas, such as rooftops, driveways, and roads, can be simulated. However, it is important to note that the identification, delineation, and aggregation of these four sub-areas may require significant site information not readily available from aerial photos, storm drainage, and topography information. In other words, a site visit and detailed inspection of the catchment, and identification of what measures in Area B will be used to disconnect imperviousness are necessary to adequately represent the connectivity of the catchment.

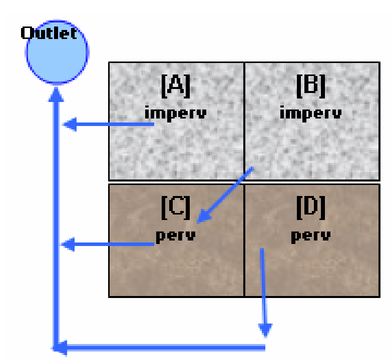


Figure 7.5 - Impervious/Pervious Connectivity Illustration

[1] Pollutant removal not associated with volume losses is based on average effluent concentrations data for BMPs found in the ASCE International BMP Database (www.bmpdatabase.org). However fine sediment (<20 um) removal is based on theoretical settling, which is internally simulated in SWMM.

7.1.2.2 Primary Pervious Conveyance

In addition to the connectivity of the pervious and impervious areas, the user has the option to route runoff from these areas either directly to the storm drain (or BMP treatment train) or to a primary pervious conveyance system. This option is intended to account for potential volume losses in pervious conveyance systems, such as roadside ditches and soft bottom channels. A length and constant loss rate must be provided if it has been specified that any of the sub-areas are routed to a pervious conveyance. Because the entire catchment is simulated as being routed to the conveyance, the representative length should be chosen to best represent expected losses from the pervious portion of the primary conveyance system. Also, it is important to note that if a conveyance system is subject to exfiltration via groundwater seeps there is currently no way to account for this added volume since soil moisture accounting and subsurface flow are not simulated.

7.1.2.3 Soils and Vegetation

The soils and vegetation in the pervious areas of the catchment (Areas C and D) are used as surrogates for several hydrologic parameters. The user has an option to use either soil texture classes (e.g., sandy loam, etc.) or hydrologic soil groups (A, B, C, or D) for defining soil types. For each soil type, the percent of the total pervious area occupied by that soil type must be provided. The soil type is the basis for estimating infiltration parameters, which in the model uses the Green-Ampt infiltration equation; the parameters for which are saturated hydraulic conductivity, soil suction head, and effective porosity (soil moisture deficit). Default values for these parameters for each soil type are contained in the *Lookup1 Hydrology* sheet of the PLRE-STS.

Similar to soils, the area breakdown as percent of pervious area is also required for each vegetation type. Currently there are five default vegetation types to choose from including shrub, herbaceous, tree (open canopy), tree (closed canopy), and non-vegetated. Up to five additional vegetation types may be added by the user. Monthly evapotranspiration rates from vegetated areas are estimated using the landscape coefficient method (Costello et al. 2000). The landscape coefficient (KL) is the product of three parameters, species (Ks), density (Kd), and microclimate (Km), and is used to adjust the reference evapotranspiration rate for a particular area. Default landscape coefficient parameter values for each vegetation type are included in the *Lookup1 Hydrology* sheet of the PLRE-STS. Note that microclimate is a site-specific parameter and may be adjusted based on sun and wind exposure (see Costello et al. 2000 for details) or used for calibration. The other default parameters associated with vegetation type include depression storage and snowmelt coefficients and may be modified in the *Lookup1 Hydrology* sheet. The default depression storage values correspond to the estimated rainfall interception provided by each vegetation type based on literature review. Due to lack of sufficient information, the default values for the snowmelt coefficients do not currently vary by vegetation type, but are included as adjustable parameters if data become available or for calibration purposes (see SWMM Manual for more information on snowmelt modeling).

7.1.2.4 Private BMP Implementation

Private BMP implementation can be represented in the methodology as a hydrologic reduction in storm water runoff through changes in impervious area accounting. There are currently two suggested methods for representing private BMP implementation in the methodology. Both methods have some limitations in their representation of actual practice. Section 9 recommends refinement to the methodology and associated PLRE-STS to develop more robust accounting and evaluation tools for private BMP implementation. The remainder of this section briefly describes the two suggested methods.

Method 1 - Impervious/Pervious Area Connectivity Representation
Section 7.1.2.1 above describes the lumped-parameter method used to represent catchment characteristics for impervious area, pervious area, and associated connectivity for storm water runoff calculations. To estimate the hydrologic effects of increased private BMP implementation, the amount of directly connected impervious area (Area A, Figure 7.5) can be reduced relative to the proposed level of private BMP implementation. The amount of impervious area deducted from Area A is then added to the impervious area for Area B (Figure 7.5). The impervious area for Area B is routed to a pervious subarea (Area C) before excess flow is routed to the catchment outlet. Using this method, total storm water runoff at the catchment outlet will decrease due to the conversion of connected private impervious area to disconnected private impervious area. The overall reduction in storm water runoff will be dependent upon the relative areas of Area B and Area C, the soil properties for pervious areas, and the long-term hydrologic record of storm intensities.

The average annual runoff calculated from the lumped-parameter hydrologic simulation is distributed in the methodology among land use categories within a catchment based on the relative area of each land use category and the representative directly connected impervious area for each land use category. Through the implementation of private BMPs the amount of directly connected impervious area within a specified land use category will likely decrease and thus runoff from the land use category will likely decrease. To account for this change within the PLRE-STS the percentage of directly connected impervious area may be modified in the Input2 Quality sheet of the PLRE-STS (Figure 7.8).

Method 2 - Impervious Area Mitigation
If the impervious area associated with private property has approved BMPs in place, then based on current regulations the private BMPs are assumed to detain and infiltrate runoff from impervious area for at least the 20-year 1-hour storm. While the hydrologic simulation within this methodology relies on continuous modeling and the 20-year 1-hour storm is an event based requirement, the latter requirement is a significant runoff volume which will not be exceeded during the continuous modeling except in the most extreme events. Given this caveat, it may be reasonable to assume that approved BMPs are adequately mitigating runoff from impervious area through storage and infiltration. Thus the impervious area associated with approved private BMPs does not need to be accounted for in the runoff calculation. For example, if a 20 acre catchment included 2 acres of impervious area that was mitigated through approved private BMPs, then the catchment size used for runoff calculations would be 18 acres.

7.1.3 BMP Hydraulics

To simulate the hydraulics of BMPs at the downstream end of a catchment, the Storage-Treatment Block of SWMM is executed by the PLRE-STS after the user inputs BMP design and treatment train routing information.

7.1.3.1 Flow-Based vs. Volume-Based BMPs

For the purposes of BMP hydraulics, BMPs are classified as either flow-based or volume-based. Flow-based BMPs have limited storage volume and are designed to bypass flows once their water quality design flow rate (WQDFR) has been exceeded. Volume-based BMPs are designed to bypass flows once their water quality design volume (WQDV) has been exceeded. As a practical matter, a volume-based BMP will include a flow control structure at its inlet, that is designed to bypass flows exceeding a given design flow rate. Example flow-based BMPs typically include swales, media filters, and hydrodynamic devices. Example volume-based BMPs typically include detention basins, retention ponds, infiltration basins, and constructed wetlands. However depending on the specifics of the BMP design, practically any BMP may be constructed as either flow-based, volume-based, or both. It is entirely up to the user to choose whether a BMP should be treated as a flow or volume based.

With respect to water quality, no treatment credit is given to bypassed flows. Or if higher flows are not bypassed, but are allowed to flow through the BMP, the model assumes again no credit for treatment. For example, vegetated swales are generally not expected to function effectively if the depth of flow is higher than the height of vegetation even though the swale may be designed to process flows that produce higher depths.

7.1.3.2 Treatment Train Routing

The PLRE-STS allows up to three BMPs to be configured into a treatment train. The BMPs may be placed in series, such that treated flows from one BMP are treated by a downstream BMP, or they may be placed in parallel, such that bypassed flows from one BMP are treated by a downstream BMP. With the various combinations of treated and bypassed flows for three BMPs, there are a total of 21 possible treatment train configurations. Figure 7.6 includes three example treatment train configurations.

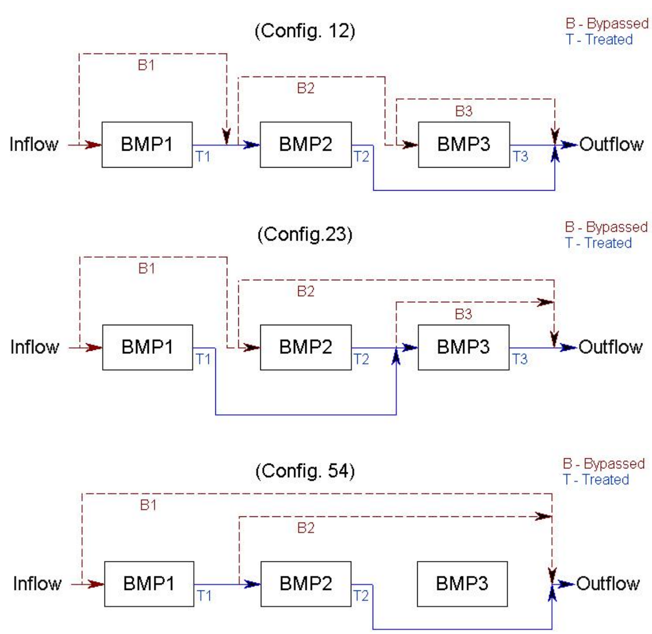


Figure 7.6 - Example: Treatment Train Configurations

7.1.3.3 Design Characteristics

In addition to specifying the BMP type and the treatment train configuration, several design related inputs must also be supplied in order to simulate BMP hydraulics. Some constants are required for all BMP types, while others are specific to the chosen flow regime (i.e. volume-based or flow-based). Constants required for all BMPs include infiltrative loss rate and length-to-width ratio. For flow-based BMPs the WQDFR is required, but it is optional for volume-based BMPs. Therefore, if a volume-based BMP does not have an inlet flow rate restriction, the WQDFR should be set equal to zero and bypass of the volume-based BMP will be regulated by available storage.

In addition to the above parameters, flow-based BMPs also require an estimated characteristic footprint area. This area is used with the length-to-width ratio for determining the hydraulic residence time (HRT) in the BMP, which affects fine particulate settling and infiltrative losses (if simulated).

For volume-based BMPs, several additional parameter values are required including the water quality design volume and depth, permanent wet pool volume and depth, stage-discharge characteristic, and the brim-full draw down time. If a wet pond or wetland is being simulated, a permanent wet pool volume and depth should be provided in addition to the water quality design volume and depth. The stage-discharge characteristic provides the option to either use the default stage-area-discharge curve or provide a user-supplied curve. The brim-full draw down time is the drain time for discharging the entire water quality design depth and the user currently has the option of specifying between 24 and 72 hours (in various increments) for the default stage discharge curve. If a user-supplied stage-discharge characteristic is selected the user must provide the depth, area, and discharge relationship in the space provided. This option provides the greatest flexibility for BMP geometry and outlet structure design. However, it is important that the permanent pool and water quality design volumes and depths are correctly represented by the stage-area-discharge relationship. For instance, if there is a permanent pool the discharge should be zero up to the depth of the permanent pool and the final depth should be equal to the sum of the permanent pool and water quality design depths.

If the default stage-discharge characteristic is selected, then a relationship is developed using the depth, volume, and draw down information provided plus a simplified water quality design approach specified in some BMP design manuals. When the default stage-discharge characteristic is selected the geometry of the detention facility is assumed to be a cylinder. This approach specifies that the top half of the WQDV drain in one-third the brim-full draw-down time, while the bottom half drains in two-thirds the drawdown time. This approach is intended to quickly provide storage after a design storm event while providing increased retention of smaller storms. In this simplified approach a constant discharge rate is used for each half of the WQDV.

Depending on the specific application of the PLRE-STS and design stage of the BMPs, some of these input parameters may not be required. Table 7.1 summarizes the required and optional parameters for flow- and volume-based BMPs.

Table 7.1 - Design parameters for flow-based and volume-based BMPs

Parameter	Flow-Based	Volume-Based
BMP Loss Rate (in/hr)	Required	Required
WQ Design Flow Rate, Q_{design} (cfs)	Required	Optional
Length to width ratio	Required	Required
Characteristic Footprint Area (sf)	Required	
Water Quality Design Volume (cu-ft)		Required (if user chooses default stage-discharge)
Permanent Wet Pool Volume (cu-ft)		Required (if user chooses default stage-discharge)
Permanent Wet Pool Depth (ft)		Required (if user default stage-discharge)
WQ Design Depth (live storage) (ft)		Required
BMP Stage-Discharge Characteristic		Required
Brim-Full Draw Down Time (hours)		Required (if user default stage-discharge)

7.2 Pollutant Load Generation and Pollutant Source Controls

The methodology developed predicts pollutant load generation from an urbanized drainage catchment through a combination of two techniques referred to as: 1) spatially distributed source accounting, and 2) specific source accounting. Depending on drainage catchment characteristics, a user may rely on both techniques to estimate total pollutant load generation for the existing condition and the proposed water quality improvements.

Spatially distributed sources that occur throughout a significant amount of the project area are represented by the spatially distributed source accounting in the methodology. Predicted pollutant load generation attributed to spatially distributed sources is the product of the simulated long-term hydrology and the median event mean concentrations (EMCs) for each land use category[2] present in the drainage catchment. Pollutant loads are calculated simply as the product of annual runoff volume and the EMC for each land use. Annual runoff volumes are computed for each land use category by proportioning the annual average runoff volume estimated from the continuous hydrologic simulation.

Specific sources are considered to occur at specific locations within the total drainage catchment, thus the area of disturbance associated with the specific source can be accurately quantified. Specific sources of pollution may not be unique to a land use category, may occur within and across multiples land use categories, or may be an anomaly. Predicted pollutant load generation attributed to specific sources is calculated as average annual loading using various methods described in a subsequent section. Examples of specific sources of pollutant loading include disturbed areas, road sanding, and eroding gullies.

Figure 7.7 repeats the simplified flow chart of the pollutant load generation methodology included in Section 6 of this report. Figure 7.7 illustrates the primary concepts behind the spatially distributed and specific source techniques. Spatially distributed sources are defined by the land use categories present along with the relative area of each land use category. Average annual runoff calculated from the hydrologic simulation is distributed among land use categories based on the relative area of each land use category and the representative directly connected impervious area for each land use category. The distributed runoff is then multiplied by the EMC of each land use category, for each pollutant of concern, to calculate average annual pollutant load generation.

Specific sources are defined by the type of disturbance, the spatial extent of the disturbance, and the average annual delivery ratio to an index point or outfall. As shown in Figure 7.7, unlike the spatially distributed source accounting technique, the specific source accounting technique does not use the simulated long-term hydrology to estimate pollutant loading. Specific source pollutant load generation is calculated using the total area of the source disturbance times and average annual rate of pollutant delivery. This simple technique is recognized as a limitation of the methodology, implemented primarily to limit the complexity of input requirements for the

[2] A land use category in the methodology is a generalized designation for an area of land where public uses, public densities, and public impacts are considered relatively uniform.

user and to avoid the complexity of attempting to model the processes affecting load generation from specific sources.

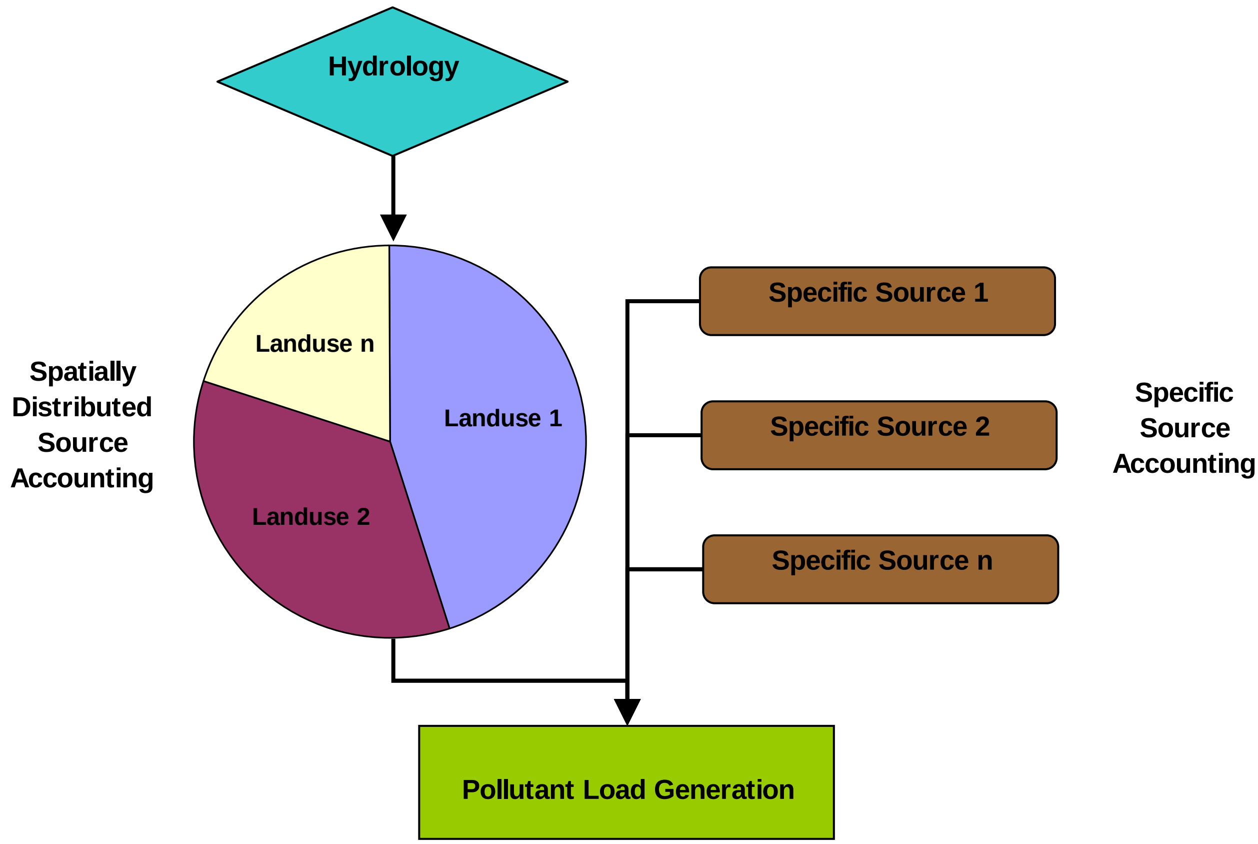


Figure 7.7 - Simplified Pollutant Load Generation Methodology

As shown in Figure 7.7, the summation of pollutant loads generated from spatially distributed sources and specific sources gives an estimate of average annual pollutant loads generated for the drainage catchment simulated.

7.2.1 Existing Condition Pollutant Load Generation

To estimate pollutant load generation for existing conditions, the spatially distributed sources and specific sources must be defined based on the drainage catchment characteristics. Data collected during typical existing conditions analysis for water quality projects is sufficient to predict pollutant load generation using the methodology. A detailed discussion regarding the assumptions and methods for calculating pollutant load generation for the existing conditions is described below.

7.2.1.1 Spatially Distributed Land Use Categories

The spatially distributed source accounting technique recognizes that non-point source pollution prediction over large urban areas is extremely complex and will produce highly variable pollutant concentrations during short time intervals. The methodology assumes that over long periods of time the most reasonable prediction of pollutant load generation from sources distributed throughout a particular land use category is derived from median EMCs based on Lake Tahoe Basin monitoring data.

In order to provide consistency between this effort and the watershed model for the Lake Tahoe TMDL the same land use categories and EMCs were used in both efforts. A detailed description of how the land use categories and EMCs were developed for the TMDL program will be included in the Draft Technical TMDL document to be released independently from this work in the summer of 2006. It should be noted that the watershed model includes computations for upland and stream erosion in addition to loads generated using EMCs for land uses. This is a fundamental difference between the current versions of the two efforts. In addition, calibration of the TMDL watershed model (to observed water quality data at major stream index points) adjusts the median EMC values.

An additional difference between the current approach for this methodology and the watershed model involves the representation of secondary roads. The watershed model currently segregates the secondary road surfaces from the adjacent land use (e.g., roads in residential areas are accounted for separately from the developed private property). The PLRE-STS approach, in contrast, envisions that roads are represented in the water quality data (and hence characteristic EMC) for that land use. In this approach, impervious area input data for each land use represent both the road surfaces in the public right-of-way and the roof and driveway surfaces on private property. The PLRE-STS does allow for secondary roads to be isolated if they are not representative of a particular land use (e.g., a secondary road through open space, or a very large secondary road in a residential area). Future application and testing of the watershed model and this methodology are needed to determine the best approach for refinement of both, including potential for use of calibration results from the watershed model to adjust EMCs in the PLRE-STS at a project scale.

Table 7.2 displays the median EMCs currently used in the methodology for each land use category and pollutant of concern.

Table 7.2 - Land Use EMCs for Spatially Distributed Source Accounting

Land Use Category	TN	DN	TP	DP	TSS	Fine Sed < 20 microns
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(% of TSS)
Residential - Single Family	1.752	0.144	0.468	0.144	56	36%
Residential - Multi-Family	2.844	0.420	0.588	0.144	150	58%
CICU - Commercial, Institutional, Communications, and Utilities	2.472	0.293	0.702	0.078	296	63%
Roads - Primary	3.924	0.720	1.980	0.096	952	63%
Roads - Secondary	2.844	0.420	0.588	0.144	150	58%
Roads - Unpaved	2.340	0.014	1.524	0.480	1,015	NA
Ski Runs	0.360	0.132	0.120	0.038	47	NA
Veg_ep1	0.164	0.011	0.034	0.029	3	NA
Veg_ep2	0.164	0.011	0.034	0.029	17	NA
Veg_ep3	0.164	0.011	0.034	0.029	34	NA

Land Use Category	TN (mg/L)	DN (mg/L)	TP (mg/L)	DP (mg/L)	TSS (mg/L)	Fine Sed < 20 microns (% of TSS)
Veg_ep4	0.164	0.011	0.034	0.029	45	NA
Veg_ep5	0.164	0.011	0.034	0.029	79	NA
Veg_Recreational	1.035	0.012	0.629	0.209	460	NA
Veg_Burned	2.340	0.014	1.524	0.480	1,015	NA
Veg_Harvest	2.340	0.014	1.524	0.480	1,015	NA
Veg_Turf	4.876	0.487	1.500	0.263	12	NA

NA – Data is not available at time of release of this report

Fine sediment particles are a significant contributing factor to the decline of lake clarity and this primary pollutant is included in the methodology, as shown in Table 7.2. Fine sediment is defined as particles with a diameter equal to or less than 20 microns in size. The methodology assumes a certain percentage of the TSS EMC is fine sediment, which may vary by land use category. The percentage of fine sediment to TSS for a land use category is based on an initial analysis of TMDL data. Fine sediment relationships in Table 7.2 should be considered preliminary. Additionally, fine sediment relationships for every land use category incorporated into the methodology were not available prior to release of this report. Research and analysis to estimate fine sediment loading is ongoing, and as new information becomes available it can easily be incorporated into the methodology.

Figure 7.8 shows the spatially distributed source accounting input block found in the *Input2 Quality* sheet within the PLRE-STS. Note that all text in blue, as well as all drop down boxes and check boxes, are available for modification by the user.

Table Q1: Spatially Distributed Source Accounting - Landuse Based

Land Use Category	Area Breakdown: % of Total Area	Area Breakdown: Average % Imperviousness	Constant Characteristic Concentration: NO3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	Fine Sed <20 micron (% TSS)
Roads - Primary	6%	90%	3.924	0.720	1.980	0.096	952	63%
CICU - Commercial, Institutior	29%	65%	2.472	0.293	0.702	0.078	296	63%
Residential - Single Family	59%	30%	1.752	0.144	0.468	0.144	56	36%
Residential - Multi-Family	6%	40%	2.844	0.420	0.588	0.144	150	58%
User Defined 1	0%	0%	0.000	0.000	0.000	0.000	1	10%
User Defined 1	0%	0%	0.000	0.000	0.000	0.000	1	10%
User Defined 2	0%	0%	0.000	0.000	0.000	0.000	2	10%
User Defined 3	0%	0%	0.000	0.000	0.000	0.000	3	10%
User Defined 4	0%	0%	0.000	0.000	0.000	0.000	4	10%
Sum	100%							

Figure 7.8 - Spatially Distributed Load Generation Input Block

7.2.1.2 Spatially Distributed Land Use Conditions

A subjective assumption is applied to the spatially distributed source accounting methodology by assuming that every project area has existing land use conditions similar to the typical land use conditions present during TMDL monitoring, which produced the EMCs shown in Table 7.2. A land use condition is defined as the relative state of water quality function, or lack thereof, within a land use category. As an example of a land use condition considered typical, the methodology assumes that the majority of monitoring data collected from the *Residential – Single Family* land use category was sampled in areas with disturbed road shoulders. In this stated example, the land use condition is disturbed road shoulders contributing to pollutant load generation in the land use category *Residential – Single Family*.

Based on the assumption of typical land use conditions represented in the TMDL EMC data, the pollutant load calculations combined with long-term hydrologic simulations are assumed to reasonably estimate pollutant load generation from spatially distributed sources on an average annual basis. The current technique does not recommend that a user modify or adjust EMCs to reflect different runoff water quality because it is assumed that the long-term simulations will account for the fluctuations seen in the TMDL water quality sampling data.

The methodology has been constrained in this manner to limit the variability of land use concentrations used by project proponents during water quality evaluations throughout the Lake Tahoe Basin. The primarily purpose of this strategy is to provide a basis for comparison between project areas and to simplify the review process. A *User-Defined* category is provided in the PLRE-STS in the event that sufficient water quality data exists that justifies defining a land use category not currently incorporated into the methodology. Additionally, the default EMCs for each land use category may be modified in the *Lookup2 Quality* worksheet of the PLRE-STS. However, project-by-project modification of these default values is not recommended as a typical practice. The use of the default values, or future modifications based on regionally adopted data analysis, will promote consistency in project evaluations and will take advantage of a large data set. Short-term project specific data may give undue weight to normal variations in water quality with storm event, season, temporary land use condition, or other spatial or temporal variance. Justification for modifying the EMC values for individual projects should be carefully considered, although project specific data will be useful in the long-term to make regional refinements.

7.2.1.3 Specific Sources

The specific source accounting method represents loading from sources of disturbance that are not attributable to a specific land use category or land use condition. A specific source is defined to occur within a finite amount of area relative to the total project area, thus the area of disturbance can be accurately quantified. Specific sources of pollution may not be unique to a land use category, may occur within and across multiple land use categories, or may not be related to any land use category.

By defining a specific source, the total pollutant load generated from a drainage catchment may be increased beyond what can be generated through the spatially distributed source accounting technique. The specific source method is included as an option recognizing that project areas often have unique disturbances or management practices that detrimentally affect water quality.

In order to apply a specific source to a pollutant load generation calculation the project proponent must ensure the specific source meets the above definition, and must justify that the specific source is not adequately represented in the TMDL EMC data. For example, a project proponent should not calculate the total area of disturbed road shoulders within a land use category and define that area as a specific source. This example is unacceptable as a specific source because 1) it does not meet the definition of a specific source, and 2) disturbed road shoulders are a land use condition that is considered typical, thus pollutant loading is assumed to be represented in the TMDL EMC data. An example of an acceptable specific source is a disturbed slope. The disturbed slope has a finite amount of area that can be accurately quantified, and it is reasonable to assume that the majority of TMDL EMC data does not represent pollutant load contributions from disturbed slopes.

Three categories of specific sources are currently incorporated into the methodology and include: road sanding; disturbed areas or slopes; and eroding channels or gullies. Each specific source category uses a different technique to estimate pollutant load generation. Limited descriptions regarding the application of each specific source accounting technique are provided in this section due to the preliminary nature of the current techniques. Developing more robust methods for specific source accounting, as well as detailed guidance, are recognized as key refinements for a future version of the methodology and PLRE-STS.

Load generation from road sanding is calculated by specifying an annual application rate, the total surface area of application, and the percent pollutant recovery. Load generation from disturbed areas or slopes is calculated using the Universal Soil Loss Equation (USLE). Load generation from eroding gullies is calculated by specifying the average annual advancement of the gully and the existing dimensions of the gully. All specific source categories require the user to estimate a delivery ratio to a drainage system or index point.

For each specific source category the quantity of pollutant loading is calculated on an average annual basis independent of hydrologic calculations made during the SWMM simulation. While this is a limitation of the methodology, it is a simplifying assumption that greatly reduces the input parameters necessary and the modeling complexity. An additional limitation to the specific source technique is that the predicted average annual loading is calculated only for TSS. Average annual loading rates for all other pollutants of concern are calculated as a ratio to TSS, where the ratios are developed based on the chemistry of Tahoe soils or road sand monitoring data from Lake Tahoe Basin.

Figure 7.9 through 7.11 provide snap shots of the specific source input blocks found in the *Input2 Quality* sheet within the PLRE-STS. Note that all text in blue, as well as all drop down boxes and check boxes, are available for modification by the user.

Table Q3: Specific Source Accounting - Road Sanding

Sand Application Rate	Total Area of Source (ft^2)	Average Annual Percent Recovery	Annual Loads from Specific Source - Road Sanding: NO3-N (lbs/year)	TKN (lbs/year)	SRP (lbs/year)	TP (lbs/year)	TSS (lbs/year)	Fine Sed <20 (lbs/year)
Light Road Sanding	5,000	70%	0.00	0.01	0.00	0.31	472	803
Heavy Road Sanding	0	80%	0.00	0.00	0.00	0.00	-	0
Heavy Road Sanding	0	90%	0.00	0.00	0.00	0.00	-	0

Figure 7.9 - Road Sanding Input Block

Table Q4: Specific Source Accounting - Surficial Erosion from Disturbed Areas							
	USLE Method						User Defined
Soil Condition	Total Area of Source (ft^2)	Percent Delivery to Drainage System	Overland Flow Length (ft)	Average Slope (%)	Soil Erodibility (K Factor)	Percent Vegetative Ground Cover	TSS Load (lbs/year) Overrides USLE Method
User Defined 2	0	75%	40	5%	0.40	0%	0
Smooth Surface - Loose Soil	0	80%	20	2%	0.40	10%	0
Smooth Surface - Loose Soil	0	80%	20	2%	0.40	20%	0
Smooth Surface - Loose Soil	0	80%	20	2%	0.40	40%	0
User Defined 2	0	80%	20	2%	0.40	80%	0

Figure 7.10 - Disturbed Area Input Block (load calculation not shown)

Table Q5: Specific Source Accounting - Gully and Channel Erosion							
	Gully and Channel Method						User Defined
Gully or Channel	Primary Direction of Erosional Advancement	Mean Annual Rate of Erosion (ft/yr)	Average Annual Percent Delivery to Drainage System	Current Length (ft)	Current Average Width (ft)	Current Average Depth (ft)	TSS Load (lbs/year) Overrides Gully Method
Gully 1	Depth	0.0	60%	10.0	5.0	2.0	0
Gully 2	Length	0.0	60%	10.0	5.0	2.0	0
Gully 3	Width	0.0	60%	10.0	5.0	2.0	0

Figure 7.11 - Eroding Gully Input Block (load calculation not shown)

7.2.2 Post-Project Pollutant Load Generation

To estimate pollutant load generation when evaluating proposed pollutant source control implementation, the spatially distributed pollutant loads are adjusted by modifying land use EMCs based on the level of spatially distributed pollutant source controls implemented. The specific source pollutant loads are adjusted by modifying the area of disturbance or severity of disturbance based upon the specific pollutant source controls implemented. A detailed discussion regarding the assumptions and methods for calculating pollutant load generation for various post-project conditions is described below.

7.2.2.1 Spatially Distributed Pollutant Source Controls

The methodology recognizes that quantifying pollutant load reduction due to the implementation of spatially distributed pollutant source controls is poorly understood. Monitoring of spatially distributed pollutant source controls is extremely complex and typically only poor statistical correlations have been produced that relate water quality improvement to the pollutant source control. Therefore, the methodology assumes the best method to represent distributed pollutant source control implementation is through a reduction in the land use EMCs as a relative improvement to the land use condition. The methodology uses a relative effectiveness index that allows the user to reduce the default land use EMCs, and therefore reduce pollutant loads, in a tiered fashion based on a relative level of pollutant source control implementation. The proposed approach allows for addressing the cumulative benefit realized from implementing multiple pollutant source controls.

The proposed approach recognizes that the default land use EMCs are not solely a function of the type of land use (e.g. residential, commercial, etc.), but also are a function of the land use conditions (e.g. disturbed road shoulders, eroding conveyance system, etc.) that may be distributed within the catchment. Therefore the implementation of distributed pollutant source controls that improve land use conditions will effectively reduce the long-term pollutant load generation from a catchment. Three distributed pollutant source control techniques are currently incorporated into the methodology: 1) stabilization of local drainages, 2) road shoulder stabilization, and 3) BMP maintenance. The user may also choose up to two additional user-defined techniques if there is reasonable justification for doing so.

For each distributed pollutant source control proposed in a land use category, the user may select the level of water quality improvement as either: Null, Tier 1, or Tier 2. In general, the Null case is assumed if no action is taken (i.e., the unadjusted default land use EMCs are used) and the Tier 2 case is assumed if the water quality improvement attributed to the pollutant source control category is considered the maximum feasible improvement. The case of Tier 1 represents a level of water quality improvement between the Null (no-action taken) and Tier 2 (maximum feasible) cases. In order to select a Tier the user must ensure that the definition of the Tier, as summarized in Table 7.3, is met by the proposed pollutant source control improvement. No credit is given for a water quality improvement that doesn't meet the minimum definition of a Tier (i.e. no rounding up). Table 7.3 provides a summary of recommended attributes that compose each tier for the three defined distributed pollutant source control techniques in the current methodology.

Table 7.3 - Summary of Spatially Distributed Pollutant Source Control Tiers by Category

Improvement	**Defining Attribute(s) of Tier**		
	Null	**Tier 1**	**Tier 2**
Stabilization of Local Drainages	Unstable condition, apparent source of sediment and associated pollutants	Stabilized condition, neither a source or sink of sediment and associated pollutants	Stable, restored, or managed condition that may actually reduce loads of sediment and associated pollutants.
Road Shoulder Stabilization	Disturbed and eroding; subject to chronic urban impacts	Areas of high erosion potential mitigated.	Erosion potential and hydrologic impacts mitigated; chronic urban disturbance behind road shoulder mitigated.
BMP Maintenance[1]	Performed less than annually	Performed at least annually in a manner similar to California Storm Water Management Plan requirements	Same as Tier 1, except performed seasonally and after significant runoff events

[1] BMP Maintenance refers to the maintenance of distributed BMPs, such as sediment removal from sand traps, catch basin inserts, and drainage facilities.

The following detailed definitions for each tier of distributed pollutant source control implementation are preliminary and provided in this report as examples. While definitions are deemed necessary to implement the described method, they are recognized as subjective interpretations that may skew actual implementation towards pollutant source controls perceived to have the easiest attainable thresholds. The final definitions for each Tier should be negotiated amongst Tahoe Basin stakeholders prior to application of the PLRE-STS.

Stabilization of Local Drainages

Null
The conveyance system, either natural or engineered, within a land use category is generally disturbed and evidence of erosion exists. Vegetation or channel armoring is not present or is minimal in spatial extent with respect to the size of the conveyance. The conveyance system appears to be significantly contributing to the annual pollutant load delivered to downstream outfall or index point.

Tier 1
The conveyance system within a land use category is stable without evidence of appreciable erosion. The conveyance system is functioning neither as a source or a sink of sediment and associated pollutants to downstream outfall or index point.

Tier 2
The conveyance system within a land use category is improving water quality and reducing pollutant loading through settling, infiltration, uptake of nutrients, and long-term retention of sediment. The conveyance system exhibits most or all of the following attributes: infiltration rates are at or above typical rates associated with the soils present; vegetation is abundant; erosion is not apparent due to protection from vegetation, channel armoring, or both; and there is a net reduction in the transportation of pollutants of concern. The conveyance system is improved and provides a load reduction to downstream outfall or index point.

Road Shoulder Stabilization

Null
The road shoulders within a land use category are disturbed and eroding. Road shoulders are subject to chronic urban disturbance including parking, vehicle traffic, and snow plow operations. The formation of rills on road shoulders clearly indicates sediment transport from a high percentage of roads in the catchment.

Tier 1
High priority road shoulders within a land use category are protected from disturbance and erosion. High priority road shoulders are defined as locations with high erosion potential due to steep slopes, exposure to significant runoff volumes and rates, and/or heavy urban disturbance. Protection of high priority road shoulders can be accomplished through a variety of improvements, including but not limited to: curb and gutter, asphalt dikes, vegetated shoulders and swales, and rock-lined roadside ditches.

Tier 2
All high priority road shoulders within a land use category meet the definition of Tier 1 and hydrologic impacts from road shoulder protection and chronic urban disturbance are mitigated. Mitigation of hydrologic impacts requires designs that either use stable pervious road shoulder improvements or distribute runoff from impervious road shoulder improvements to pervious elements frequently along the flow path. Mitigation of chronic urban disturbance requires designs that protect road shoulders from parking, vehicle traffic, and snow plow operations.

BMP Maintenance

Null
All distributed water quality improvement facilities within a land use category are maintained on a less than annual basis. See Tier 1 for a definition of maintenance. Examples of distributed water quality facilities include, but are not limited to: storm drain inlet inserts, detention pipes, sedimentation manholes, sand traps, culverts, curb and gutter, asphalt dikes, rock lined or vegetated swales, and any other decentralized storm water device.

Tier 1
All water quality improvement facilities within a land use category are maintained on an annual frequency. Maintenance involves the development of an inventory database of all water quality improvement facilities, annual inspection of all facilities, evaluation and prioritization of facilities relative to water quality function, and annual maintenance of prioritized facilities.

Tier 2
All water quality improvement facilities within a land use category are maintained on a seasonal and post-significant event frequency while meeting the definition of maintenance in Tier 1. Seasonal maintenance is defined to occur a minimum of three times annually: prior to the onset of spring runoff, prior to heavy thunderstorm activity, and prior to the heavy snowstorm activity. A significant event is defined as either a 20-year 1-hour storm, or any runoff event that exceeds the water quality design capacity of the water quality improvement facilities.

Each tier for a spatially distributed pollutant source control technique is given a relative value as shown in Table 7.4. The user may select as many of the spatially distributed source control techniques (stabilized conveyance, stabilized road shoulder, etc) and corresponding tiers of water quality improvement (Table 7.4) as proposed. The methodology allows the user to improve the conditions of each land use category independently within a drainage catchment.

Table 7.4 - Relative Effective Index for Source Controls

Level of Source Control Implementation	Relative Effectiveness Index
Null	0
Tier 1	1
Tier 2	2

Selecting multiple pollutant source control techniques within a land use category will result in a summation of the relative effectiveness index and thus increase the water quality benefit. The summed relative effectiveness index is linked to a standard statistical Z-table referencing the area of a curve under a normal distribution (Table 7.5). As the relative effectiveness index increases due to multiple pollutant source controls implemented, the corresponding Z-value increases. This corresponding area under the normal distribution curve is used as a percentage improvement to a land use EMC for a particular land use category, as shown in Table 7.5.

This subjective crediting methodology was selected because it is statistically based and future refinements may reference statistical information developed from monitoring data. Currently, the variations seen in pollutant concentrations from the available monitoring data cannot be statistically explained (Gunter 2005) and therefore standard deviations or other statistical representations of the monitoring data have not been incorporated into the methodology.

Table 7.5 - EMC Improvement Based on Summed Relative Effectiveness Index

Summed Relative Effectiveness Index	Z-Value	Area Under Curve	Percentage EMC Improvement
0	0	0	0%
1	0.2	0.0793	8%
2	0.4	0.1554	16%
3	0.6	0.2258	23%
4	0.8	0.2881	29%
5	1	0.3413	34%
6	1.2	0.3849	38%
7	1.4	0.4192	42%
8	1.6	0.4452	45%
9	1.8	0.4641	46%
10	2	0.4772	48%

7.2.2.2 Specific Pollutant Source Controls

Representation of specific pollutant source control implementation for proposed pollutant source controls is simulated by either decreasing the area of disturbance, the rate of disturbance, or both. Three categories of specific pollutant sources are currently incorporated into the methodology and include: road sanding, disturbed areas or slopes, and eroding gullies. Examples of mitigation strategies for evaluating specific pollutant source control implementation follows.

If the existing condition pollutant load generation includes road sand application, a mitigation strategy to address water quality impacts may evaluate any of the following options: 1) reducing the average annual application rate of road sand, 2) reducing the total area of road sand application, 3) increase the efficiency and/or frequency of street sweeping, and/or 4) decrease the delivery of road sand to the drainage system by decreasing connectivity. These proposed pollutant source control mitigation strategies can be quantified and evaluated to produce a future condition pollutant load generation.

For a disturbed area, a mitigation strategy could propose to revegetate and restore 70% of the disturbed area and correspondingly decreasing the pollutant load generated. If the disturbed area was completely revegetated and restored then the specific pollutant source would be omitted from the calculation for pollutant loading. Note that for this specific example, if the disturbed area was paved, the erosion source would be eliminated but the impervious area and any increase in impervious connectivity would have to be simulated in the hydrologic input characteristics for the future condition evaluation.

7.3 Storm Water Treatment

The methodology accounts for potential load reductions achieved by source controls as well as storm water treatment BMPs. Source controls are integrated directly into the pollutant load generation and hydrology elements of the PLRE-STS as discussed above in Section 7.1 and 7.2. The storm water treatment element predicts water quality improvement provided by BMPs at the downstream end of a modeled catchment.

As noted in Section 7.1, up to three BMPs can be simulated in series, parallel, or combination. Depending on the treatment train configuration chosen, pollutant loads may be reduced during each step in the treatment train due to volume losses or due to other treatment processes provided by the BMP, such as sedimentation, filtration, and pollutant uptake. Only sedimentation is simulated as a process-based treatment mechanism, while the other processes are based on empirical data of BMP performance. The following subsections briefly describe the storm water treatment element of the methodology including the influence of hydraulics and hydrology, sedimentation theory, and the empirical basis for nutrient removal.

7.3.1 Hydraulic and Hydrologic Effects

As described in Section 7.1, BMP design and routing information is used to simulate BMP hydraulics. The output of the BMP simulation includes the average annual volume bypassed, lost (infiltrated and evaporated), and treated by each simulated BMP. The volume bypassed does not receive any treatment by the BMP, but the percent volume lost (due to infiltration and evapotranspiration within the BMP) equates to an equivalent percent loss in the captured load. This assumes that pollutants are settled to the bottom or contained within the subsurface soils of the BMP and once captured the pollutants are not resuspended, or otherwise able to cycle back into the water. The treated volume that exits the BMP is the captured volume minus the lost volume. Loads associated with the treated volume are reduced based on either particle settling or effluent quality characteristics of the simulated BMP. These two treatment processes are discussed in detail below. Figure 7.12 illustrates how BMP hydraulics and hydrology affects pollutant loads.

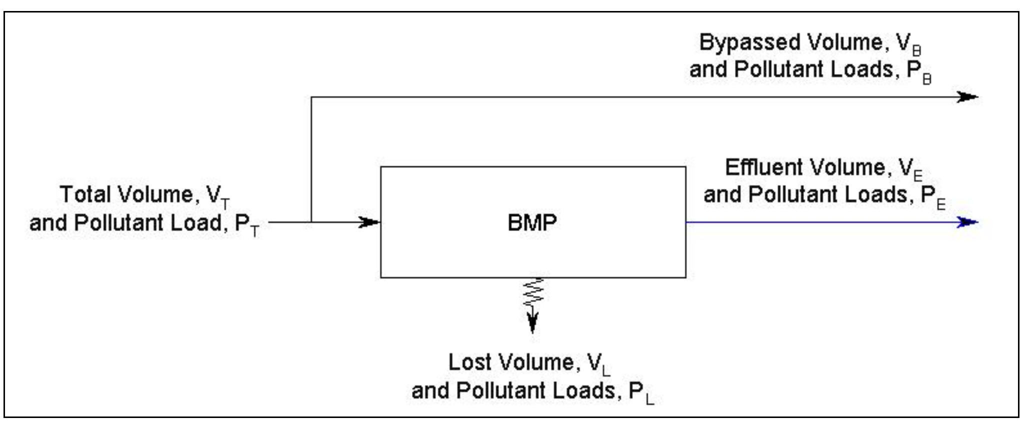


Figure 7.12 - BMP Hydraulics and Hydrology Effects on Pollutant Loads

7.3.2 Settling Theory

Fine sediment (<20 um) removal in each BMP is based on discrete particle settling simulated at each time step within the Storage-Treatment Block of SWMM. Discrete particle settling assumes that settling occurs unhindered, such that particles do not collide with each other or other obstacles. Sedimentation is a function of particle settling velocities, basin geometry, and flow velocity. Settling velocities are estimated for five particle size ranges using a modified form of Dietrich's formula derived by Jiménez et al. (2003), which predicts settling velocity as a function of particle size, shape, roundness, and density. The model includes a correction for non-quiescent settling conditions. Particle settling theory applies to gravitational processes but does not account for capture of fine sediment by vegetation or the effects vegetation may have on decreases in turbulent flow. Basin geometry is based on the length-to-width ratio, depth, and footprint area provided by the user. Using plug-flow routing, SWMM internally calculates flow velocities at each time step to account for turbulence and estimates percent removal for each particle size range. A detailed explanation of the theory and equations used for simulating sedimentation are provided in the SWMM User's Manual (Huber and Dickinson, 1988).

7.3.3 Characteristic Effluent Concentrations

For all pollutants besides fine sediment, empirical BMP performance data are used to predict pollutant removals. Characteristic effluent concentrations are used for each BMP type, recognizing that BMP performance is often restricted to an achievable effluent quality rather than a fixed percent removal dependent on influent quality (Strecker et al. 2001). As such, effluent concentrations are used to determine whether pollutant load reductions would occur based on predicted annual average influent concentrations. For instance, if an annual average influent TSS concentration of 20 mg/L is predicted and the characteristic effluent concentration for a simulated BMP is 30 mg/L, then TSS removal is assumed not to occur in the BMP. For treatment train simulation, this approach is more appropriate than percent removals because it does not apply cumulative credits for pollutant removal.

The methodology currently uses median BMP effluent concentrations from data in the International BMP Database (www.bmpdatabase.org) as default values. While it is recognized that the performance data contained in the BMP database may differ from BMPs in the Tahoe Basin (Strecker et al. 2005). Tahoe-specific data are currently too limited to develop statistically robust performance estimates for many BMP types. For instance, based on the research by Strecker et al. (2005), the available Tahoe BMP performance data lacks a statistically significant number of BMPs to adequately characterize performance for the variety of BMPs that may need to be simulated as end-of-pipe treatment. Table 7.6, presented by Strecker et al. (2005), summarizes the available Tahoe BMP data. Note that the majority of BMPs listed in the table are sediment traps/basins (10) with only a limited number of detention basins (4), wetlands (1), and swales (1 rock-lined). The other BMPs listed are better classified as source controls (e.g., revegetation) rather than centralized, structural treatment BMPs. Furthermore, additional data gaps exist with the water quality parameters monitored since many studies did not include dissolved nutrients in their parameter suite. Despite these significant data limitations, a comparison of the median effluent concentrations of BMPs in the ASCE BMP database to the Tahoe BMPs is shown in Table 7.7. As shown in the table, nearly all of the median concentrations for wetlands and detention basins are close in relative magnitude, with the exception of the median nitrate concentration for detention basins. However, due to the limited number of data points, it would be difficult to show a statistically significant difference between the International BMP database values and the Tahoe BMPs. While the PLRE-STS currently uses the BMP database effluent concentrations as default values for the reasons discussed above, the default BMP performance values can be easily updated as more Tahoe data become available.

Table 7.6 - Mean Effluent Quality of Tahoe Basin BMPs (Strecker et al., 2005)

Sites/Source Study	BMP type	TSS mg/L	TP µg/L	DP µg/L	NO3-N µg/L	NH4-N µg/L	TKN µg/L
Apache (1/3)	Sediment basin	12		86	8	11	318
Apache (2/3)	Sand Trap	80		22	83	0	92
Apache (3/3)	Sand Trap	5		33	79	8	49
Cave Rock (1/3)	Lined extended sediment/detention	177	232		89		
Blackwood Creek	Check dam, diversion structure, enhanced SEZ	5	9		24		
Upper Edgewood / Kingsbury 1	Sediment retention basin, curb and gutter, rock ditch	190	180				
Upper Edgewood / Kingsbury 2	Sediment retention basin	190	180				
Elks club	Linear detention basin	19	53	27	53	33	432
Griff Creek	Small in-channel sediment retention basin	5	13		15		
Tahoe City	Wetland Basin	5	100	61	102	9	NA
Marlette Creek	Revegetation	5	18		36		
Pioneer Trail	Natural, seasonally wet meadow	23	36		54	13	336
Sante Fe Road	Check dam, diversion structure, enhanced	20	35		85		
Sawmill Pond	Restoration of historic gravel pit	4	19		49		
Saxon Creek	Landfill covered, revegetation	19	17		8		
Eloise Basin,	Detention Basin	10	227	188	198	16	1728
Northwood Ditch	Detention Basin	8	72	38	40	7	372
Village Green Pond,	Detention Basin	NA	805	560	8	33	3381
Tahoe Airport and	Sand Trap	422	0.4	0.07	0.3	0.4	1.7
Tahoe Mountain	Paved drainage ditch	6	44		153		
North Upper	Unspecified	1420		15	27	17	1977
Cave Rock (2/3)	Double barreled sand trap	370	530				
Cave Rock (3/3)	Rock lined ditch	157	330				

.

Table 7.7 - Median BMP Effluent Quality from ASCE International Database

BMP Type	NO3-N mg/L	TKN mg/L	DP mg/L	TP mg/L	TSS mg/L
ASCE BMP Database Median Effluent Quality					
Detention Basin	0.68	1.50	0.07	0.29	32
Wet Pond	0.10	0.95	0.04	0.10	9.7
Media Filter	0.68	1.50	0.04	0.14	13
Wetland Basin or Channel	0.19	1.25	0.04	0.08	7.0
Hydrodynamic Device	0.70	0.80	0.04	0.14	57
Biofilter (Swale)	0.28	1.43	0.05	0.24	22
Tahoe BMPs Median Effluent Quality					
Sand Trap/Sediment Basins	0.024	0.071	0.028	0.035	50
Detention Basin	0.053	1.08	0.113	0.227	14.5
Wetland Basin	0.102		0.061	0.1	5
Rock-Lined Swale				0.33	157

8.0 SENSITIVITY AND LIMITATIONS

While an extensive sensitivity analysis of the PLRE-STS is beyond the scope of this project, several parameters have been observed to influence the hydrologic and water quality results more than others. In fact, during the development of the PLRE-STS, effort was made to include parameters known to be sensitive in the primary data entry sheets. Furthermore, while inherent limitations of the PLRE-STS and overall methodology were recognized early in the planning and development stages, testing of the PLRE-STS has helped identify additional limitations not originally identified. The following subsections discuss some of the most sensitive model parameters and the limitations that have been recognized to date. More testing and analysis are certainly needed with regard to sensitivity and the identification of limitations. Section 9 describes some of the recommended next steps that could be made to the methodology to help overcome some of these limitations.

8.1 Hydrologic Sensitivity

For the runoff hydrology simulations, the most sensitive hydrologic parameters appear to be total impervious area, impervious area connectivity, soil type, and pervious conveyance length combined with loss rate. Average annual runoff volumes are not highly sensitive to catchment slope and vegetation type, but the duration of high flow rates is mildly sensitive to slope.

For the BMP hydraulic simulations, the most sensitive parameters affecting hydrologic results appear to be BMP loss rates, water quality design volume (active storage), water quality design flow rate, and the stage-area-discharge relationship. The latter three parameters greatly affect the average annual percent capture volumes and the ultimate flow-duration characteristics of the outflow.

8.2 Water Quality Sensitivity

The average annual loads reaching the outlet or BMP treatment train are sensitive to nearly all of the load generation component parameters. The land use types, distribution of land uses, and assigned impervious values directly affect the distributed source loads, especially when comparing highly urbanized land uses with undisturbed open space.

Specific source parameters can have a significant affect on pollutant loading with the area of the source being the most sensitive for road sanding and disturbed areas; and the length, width, and depth being the most sensitive for gully advancement. The specific source accounting methods currently incorporated into the methodology should be considered preliminary representations that illustrate a particular approach. More refinement and testing of these methods are needed, and the reader is cautioned that pollutant load generation from specific source accounting is subjective and sensitive to input assumptions.

Due to the use of characteristic effluent concentrations for BMPs, the level of pollutant removal provided by a BMP is sensitive the BMP type and the effluent concentration used, relative to the level of source control provided in the catchment. If a high level of source control is provided, the BMPs are limited in their ability to continue reducing pollutant loads except via volume losses. The same applies to treatment trains.

8.3 Hydrologic Limitations

The following lists some of the current hydrologic limitations of the methodology.

1. Results dependent on MM5 data.
   The MM5 data currently supplies all necessary meteorological data to the methodology, allowing for site specific considerations, such as orographic effects. The MM5 data set is a very powerful tool that greatly simplifies data entry needs while providing project specific meteorological data. However, significant limitations in accuracy are currently recognized in this data set. Refinement and recalibration of the MM5 data set is recognized as a top priority for future work implemented by the TMDL program.

2. Single catchment simulations and no hydraulic routing.
   The current methodology only allows for the simulation of one catchment with the option to route runoff from impervious/pervious areas either directly to the storm drain (or BMP treatment train) or to a primary pervious conveyance system. The primary conveyance is simulated as a long, skinny catchment rather than a channel with a defined cross-section, so the volume losses in the conveyance may be underestimated due to a smaller wetted perimeter. To simulate multiple catchments, separate data sets and simulations are required. If two catchments discharge to a single BMP (or treatment train) the effects of hydraulic routing are not captured.

3. Lumped catchment parameters.
   Soils and vegetation data information are area weighted, so localized hydrologic effects are lumped. If the soils or vegetation of a pervious area receiving impervious runoff are different than other pervious areas within a catchment, there currently is no way to account for this difference. Similarly, the current methods do not allow for differentiation of impervious area connectivity for different land uses within a particular drainage catchment. For small drainage areas, these limitations are likely insignificant considering other factors influencing runoff volumes. However, as the drainage area becomes larger, the lumped parameter assumption becomes less valid. If desired, multiple drainage catchments can be created for increased resolution of the lumped-parameter representation, but this approach may quickly lead to a large number of individual drainage catchment simulations in a project area.

4. Constant loss rates in BMPs.
   The use of constant loss rates does not account for increases in infiltration rates due to increases in hydraulic head, or effects of soil moisture on infiltration. For infiltration-based BMPs, the loss rate may be set equal to the loss rate that would occur at average depth, but losses during small storms may be overestimated and losses during large storms underestimated. Additionally, the constant loss rate assumption will not account for decreases in infiltration rates that may occur over time within a BMP.

5. Bypassed volume is computed from water quality design parameters.
   For the purpose of the water quality computations, the volume bypassing a BMP is computed as the portion of flows that exceeds the water quality design volume or water quality design flow rate. This may occur without a physical bypass (e.g., design flow rate

for a vegetated swale is exceeded, or design volume for a detention basin is exceeded). The treatment of these flows as bypassed is an assumption, and does not account for potential effects such as resuspension of sediment in the BMP. Designs that include physical bypasses (e.g., flow splitters at the inlet) and that route all flow through the BMP are treated essentially equally, but may not perform the same. In addition, the methodology allows the user to route bypassed flows to a location other than treated flows, but this may not be physically possible if the design does not include an actual bypass structure.

6. Total runoff volume distributed among land uses based on imperviousness.
   Due to the lumped parameter assumption, the runoff volume generated from each land use type is not explicitly tracked. Therefore, in order to estimate loads from each land use, the total runoff volume from the catchment is distributed among the different land uses based on imperviousness. If significant losses occur due to disconnected impervious area or in the primary conveyance, the load reduction associated with those losses may not be accurately credited to the land use with which they originate.

8.4 Water Quality Limitations

The following lists some of the current water quality limitations of the methodology regarding estimates of pollutant load generation and storm water treatment.

1. Spatially distributed pollutant source controls implementation given a subjective benefit.
   Discussions with Tahoe agencies, national programs and researchers, and a literature search revealed that very little data exists defining the quality of runoff measured due to pollutant source control implementation. This is a significant gap in knowledge, particularly because the agreed upon approach (preferred design approach) for implementation of water quality improvement projects within the Tahoe Basin emphasizes pollutant source control. To reflect water quality improvement for pollutant source control implementation the median EMCs by land use category are reduced using a statistical approach that is subjective. In this manner the data for existing conditions are adjusted to represent future conditions, but this may not be an accurate approach. Additionally, the method requires defining subjective tiers or thresholds for credit from pollutant source control implementation. While these definitions are necessary to implement the selected method, they may unduly influence the choice of source controls to be implemented. Bias may be unintentionally introduced by defining subjective tiers in the absence of adequate data, and if applied in project planning, could skew actual implementation towards pollutant source controls that are easiest to implement or appear to give the biggest benefit in the methodology.

2. Specific pollutant source loading techniques are not physically based.
   Currently, three specific pollutant source loading techniques are included in the methodology: road sand application, disturbed area erosion, and gully erosion. These techniques provide limited methods for estimating pollutant delivery from these potential sources on an average annual basis. Minimal guidance is provided regarding reasonable estimation of input parameters. Additionally, the techniques only directly calculate

average annual TSS delivery. All other pollutants of concern are based on ratios to TSS, developed from Tahoe soils and road sand data.

3. <u>Pollutant load generation techniques do not protect against potential double counting.</u>
   Spatially distributed source accounting and specific source accounting techniques are available to allow project proponents to customize pollutant load generation estimates to their particular project area. For example, the distributed source accounting technique includes highways as a land use category. The specific source accounting technique allows a user to define road sanding as a specific source. If a user were to define highway road sanding as a specific source this may result in double-counting of pollutants represented in the median EMCs used for the highway land use category in the spatially distributed source accounting technique.

4. <u>Delivery ratios user-defined.</u>
   For specific pollutant source accounting, a user must currently estimate and input the ratio relating pollutants generated to pollutants ultimately delivered to the outfall or index point. Very little guidance is available for estimating delivery ratios and currently the user must use best professional judgment.

5. <u>BMP maintenance relative to improved water quality is subjective.</u>
   Estimating the effectiveness of maintenance on BMP performance is difficult. Water quality project facilities are typically maintained by public works departments and improvement districts. The major current sources of grant funds for water quality projects provide funds for construction but not for maintenance of facilities. Although most implementers have a systematic maintenance program, the effects of limited maintenance funds on BMP performance is not known. The current simulations can extend for up to 30 years. The amount of BMP maintenance assumed over the simulation time period can significantly affect the choice of input parameters, which are currently defined as constants. Examples include the infiltration rate of the BMP, active storage, and depth.

6. <u>BMP effluent quality based on International BMP Database.</u>
   The current BMP effluent quality data is based on the International BMP Database for structural BMPs to define potential treatment thresholds. Tahoe specific data was evaluated, but in general was found to lack an adequate number of studies and typically did not reference design information. Additionally, very little monitoring data is available on particle size distributions in runoff, fractionation of nutrient loads, effectiveness of BMPs on the fine sediment and dissolved nutrient fractions, and the variability in effectiveness under different hydraulic design conditions (e.g., residence time).

7. <u>High amount of variability in land use EMC data used.</u>
   The EMCs used in the methodology were developed from Tahoe Basin monitoring data as part of the Lake Tahoe TMDL Program and are used in both the watershed model and this methodology. TMDL data and analysis was an extensive effort, and the data is considered the best available for estimating pollutant loads from various land use categories. But the current data set contains a high amount of variability and few

statistically relevant correlations have been made. The methodology assumes that the combination of long term temporal averaging of hydrology and the EMC data will reasonably estimate average annual pollutant loads.

9.0 RECOMMENDED NEXT STEPS

The methodology developed for this project is a major step in the ongoing development of quantitative analytical tools for estimating Tahoe Basin pollutant loads. The primary work product for this project is the conceptual framework for computation of pollutant loads – integrating hydrology, pollutant sources and source controls, and the effects of treatment BMPs in a single methodology. The scope of work for this project did not specify a model or calculation tool as a work product, but development of a spreadsheet model assisted the project team to develop and test the underlying concepts for the methodology. The Project Advisory Committee (PAC) supported development of a spreadsheet model to advance efforts towards providing a quantitative methodology. The resulting Pollutant Load Reduction Estimator – Spreadsheet Tool for Tahoe Storm Water (PLRE-STS) is a compilation of methods that together form a methodology for estimating pollutant loads from a small to medium sized drainage catchment.

The conceptual methodology is a major advance in the approach to calculating pollutant load reductions in the Tahoe Basin, but it should be recognized that the computational tools have only been developed to the prototype level at present. In the context of this report, "prototype" means that a relatively complete computational tool is ready for initial testing and further development. Additional development of the methodology and computational methods in the PLRE-STS are needed so that they can be used broadly by project proponents and accepted by regulatory agencies.

This section summarizes recommended next steps in development of the methodology and to the computational tools used for its implementation. The following points regarding the potential development of the methodology provide context for this section:

- Although operational in its current form, the project team, PAC, and TMDL team recognize that the prototype version of the PLRE-STS is not completely ready for general application to project evaluation and pollutant load crediting applications. Further development, testing, parameter verification, and refinement into a user-friendly and robust computational tool are needed.

- The appropriate steps in development and implementation of the methodology are influenced by related efforts in the TMDL program. These include development of the LSPC watershed model and development of the Integrated Water Quality Management Strategy for the TMDL. Further development of the methodology should be coordinated with these efforts to ensure consistency in the application of available data, consistency in general approach, and perhaps more direct linkage in computational methods. Options exist for computational development of the methodology varying from refining the PLRE-STS independently to complete integration with the LSPC model, and these options need to be considered in future development steps.

- Technical improvements to the methodology also depend to some extent on external factors. The availability of data has been noted as a constraint in various areas of the methodology development. Gaps in available water quality and BMP performance data in the Lake Tahoe Basin will be reduced over an extended period of time. The process of improving the methodology and the tools used to implement it will be a continuous cycle of data- and experience-driven refinement. However, some data are available in the near term and some significant improvements are possible now through testing of the methodology and incorporation of data or methods from other geographic areas and comprehensive storm water programs, such as Caltrans.

- The project team and the PAC recognize that implementation of a first version of the methodology is a high priority to meet the needs of the TMDL program and implementers. In addition, valuable insight can likely be gained from test applications at the project scale. For these reasons, a two step process is recommended – a first step for testing and refinements of the methodology and the PLRE-STS by a small team of technical specialists (Section 9.6), and a second beta testing program involving project proponents (Section 9.7).

9.1 Overview of Recommended Development Process

Recognizing that some uncertainty exists in prioritizing improvements to the methodology and development of related information, Figure 9.1 provides an overview of the recommended development process. Each individual box within Figure 9.1 represents a stage of the development process as foreseen by the PAC. Boxes that are dashed represent external efforts that will support or complement the methodology. Boxes that are not dashed are tasks directly involving further development of the methodology and PLRE-STS.

Note that the following discussion uses **bold letters** when describing the individual development stages shown in Figure 9.1. The **Methodology/Prototype PLRE-STS** is the end product of this current project. The PAC has identified **Recommended Improvements** (Section 9.5) to improve the robustness, functionality, and relative accuracy of the PLRE-STS methodology. A linkage between the LSPC **Watershed Model** and **Recommended Improvements** is shown in Figure 9.1 to identify options for ensuring compatibility between the two efforts, ranging from the use of consistent data sets and generally consistent methodologies to direct computational linkages. A vision is needed for the relationship between the two tools prior to further development of the PLRE-STS.

Recommended Improvements (Section 9.5) are shown in Figure 9.1 leading to **Initial Improvements** and **Future Improvements.** The division into two development stages recognizes that accomplishment of all tasks listed in **Recommended Improvements** prior to release of a **Beta Version** of the PLRE-STS is not be feasible. **Initial Improvements** in both technical methods and functionality of the PLRE-STS are considered feasible, and will be supported by external data and information available in the near term. This will produce a functional tool for beta testing in Tahoe Basin project applications. However, some improvements will likely be deferred due to budget constraints or availability of additional needed data and information until after the release of a **Beta Version**.

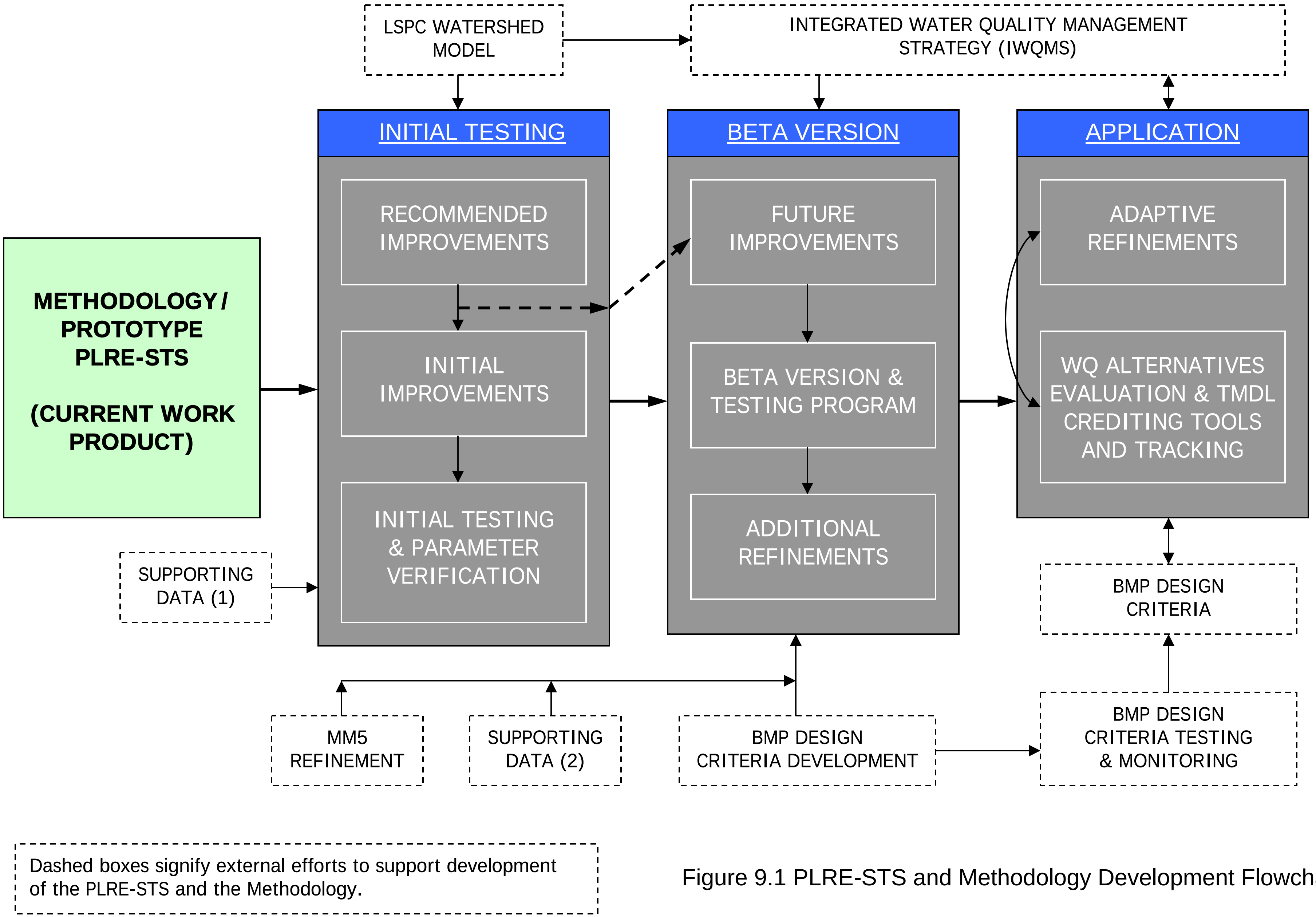


Figure 9.1 PLRE-STS and Methodology Development Flowchart

After completion of **Initial Improvements** the PAC recommends **Initial Testing and Parameter Verification** (Section 9.6) by a small team of technical specialists to evaluate the methodology and the overall performance of the PLRE-STS. This step would test the PLRE-STS against observed data from the Tahoe Basin, conduct sensitivity analyses for input parameters, refine and calibrate default parameters to the extent feasible, and begin to build a body of experience in application of the PLRE-STS to actual conditions.

After completion of **Initial Testing and Parameter Verification** a "**Beta Version"** release of the PLRE-STS is recommended. **Beta Version**, as used here, means a computational tool that has undergone sufficient testing and development to be released for independent application and testing by intended users at the project scale. This stage implies a tool that is computationally robust, user-friendly, and is expected to give reasonable results when applied by users with a moderate level of skill. Beta testing, to be effective, will require a structured process for application, technical support, and feedback for improvements in the methodology. The **Beta Version and Testing** step involves production of this version and required documentation, development of a testing protocol, training, distribution and technical support for application of the Beta Version in a structured program, and a process for user feedback to produce additional improvements in the methodology and PLRE-STS. At this time, it is anticipated that **MM5 Refinement** may be available about at the time of development of the **Beta Version** and could be incorporated into this version.

Additional Refinements are expected based on the outcome of the beta testing, and on the availability of an increasing body of data and information to support a shift towards more process-based algorithms where feasible. These **Additional Refinements** will likely be supported by needs as developed in the Integrated Water Quality Management Strategy (**IWQMS**) for Phase II of the TMDL and the development of **BMP Design Criteria**. The IWQMS is expected to develop estimates of maximum feasible load reduction (MFLR) for various source categories and to further evaluate potential BMP effectiveness for reducing loads by land use type. Integration between the development of the PLRE-STS and the data, methods, and load reduction estimates for the portion of IWQMS related to storm water is important to ensure overall consistency in the TMDL program.

The development process for **BMP Design Criteria** is not well defined, but the Corps of Engineers is pursuing this work in cooperation with project implementers. Because performance in many BMPs varies significantly with hydraulic design (e.g., residence time or hydraulic loading, turbulence, short-circuiting, vegetative roughness, depth, velocity, etc.) a preferred approach would be to link performance estimates in the PLRE-STS with specific design criteria. This approach would allow variable performance, based on typical site constraints such as surface area, soils, vegetation, to be estimated directly in the PLRE-STS. In turn, the effects of BMP design criteria on BMP performance at multiple sites could be analyzed based on key design criteria (**BMP Design Criteria Monitoring and Testing**) to improve load reduction estimates. This approach could eventually link BMP design criteria and load reduction estimates in an integrated, objective system for evaluating project alternatives. Although the **BMP Design Criteria** development process needs to be further defined, this concept is illustrated in Figure 9.1. It should be noted that it will likely only be possible to use the methodology to quantify the effects on performance of a few key design parameters from field studies, given the large number of design, runoff, and site variables.

After **Additional Refinements** are made based on Beta Testing, inputs from the IWQMS, and BMP Design Criteria Development, a version of the PLRE-STS will be ready for use in projects as a **Water Quality Alternatives Evaluation, TMDL Crediting, and Pollutant Load Reduction Tracking Tool**. These purposes are closely related, but procedures for crediting and tracking applications could require some additional definition that is not shown in Figure 9.1. The process of improving the PLRE-STS methodology is expected to occur over many years in a continuous cycle of data- and experience-driven **Adaptive Refinements** as more supporting data is developed and scientific understanding progresses. Key to this effort will be the initiation and commitment to a long-term monitoring program than can support and inform a continuous improvement cycle for **Adaptive Refinements**.

9.2 Accuracy and Application of Computational Results

In any modeling application that supports planning or implementation decisions, the question of accuracy arises. The compiled methodology is subject to considerable uncertainty in several areas. Absolute accuracy was not expected in the prototype, and it is important that expectations for future accuracy are reasonable as the development of the methodology moves forward.

It is helpful to consider the required accuracy in the context of potential applications, and to distinguish between absolute accuracy (prediction vs. actual) and relative accuracy (comparison between two predictions). Suggested targets include:

> Pollutant load reduction tracking, TMDL program planning, and crediting – The methodology should accurately represent, on average, the load reductions associated with projects and plans at a regional scale. Absolute accuracy is desired, but not necessarily required at the project scale. Absolute accuracy is needed for estimating load reductions to Lake Tahoe, considering average effectiveness of projects. The level of accuracy required needs to be consistent with expected accuracy for other TMDL efforts, such as the LSPC Watershed model, Lake Clarity Model, and the TMDL load allocations. Relative accuracy is needed to estimate effectiveness of different strategies by source category and land use.
>
> Project scale alternatives evaluation – Sufficient relative accuracy is required to evaluate alternatives, including those with substantially different configurations. Absolute accuracy is desirable, but not required.

The extent to which these targets are met will depend on further development of the computational tools, and probably more importantly, on the experience and judgment of implementing and regulatory agencies.

The PLRE-STS methodology includes the complexities of hydrologic modeling and multiple levels of additional complexity for water quality estimates. The accuracy of the hydrologic components is potentially higher than the water quality components, due to the natural variability in pollutant concentrations and loads and the relative difficulty in judging the reasonableness of water quality results. Like a hydrologic model, the accuracy obtained in an application depends on the experience of the modeler and the quality of input data as much as on the computational tool itself. The model provides a framework for producing quantitative estimates – expected accuracy is not assigned to the model, but to applications where sufficient data are available to compare results to observed values.

Pollutant load estimates in the PLRE-STS are derived from a combination of site specific modeling (e.g., hydrology, settling performance) and statistically-derived default values (e.g., median EMCs, median effluent concentrations). Computations are made on a short time interval (1 hour) but results are reported in terms of mean annual loads. Therefore, traditional calibration and validation techniques using site specific event data does not provide a definitive means to estimate accuracy. Event data for pollutant loads from urban areas in the Tahoe Basin is limited, and annual load data is scarce. Verification of model results against available data can improve confidence in predictions and give insight into appropriate techniques for application to specific sites. However, it should be expected that computations will often be performed in situations and at sites where sufficient data are not available to even estimate the resulting accuracy. This situation is not unlike hydrologic modeling in ungaged watersheds, where the absolute accuracy of results is not really known, but results are evaluated for reasonableness and accepted on the basis of standard practice.

The initial testing and parameter verification step is necessary to better define expected accuracy in various applications. This step will also provide insight into both the expected absolute and relative accuracy of predictions at specific sites, and help define methods for assessing sensitivity to input parameters, and provide experience in the interpretation of results. This experience should be used to produce guidance on the interpretation of results, considering expected absolute and relative accuracy, to be included with the documentation for the Beta Version.

9.3 Linkage to TMDL Watershed Model

Ultimately, the results from this effort and other tools developed for estimating pollutant load reduction in the Tahoe Basin should be compatible and consistent with the LSPC Watershed Model in order to evaluate basin-wide effectiveness of load reduction strategies and cumulative benefit of water quality improvement projects. Various levels of compatibility or direct linkage may be considered from both technical (i.e., computational) and program implementation perspectives. They include:

a) Compatibility and consistency in input data sets;
b) Application of consistent or similar algorithms for load computations;
c) Translation or scaling of results from one method/model to another;
d) Direct output-input linkage for results from one method/model to another.

The above options require evaluation based on feasibility, cost, and effectiveness. Options of linkage exist for computational development of the methodology varying from refining the PLRE-STS to complete integration with the Watershed Model, and these options need to be considered in future development steps. Regardless of the level of linkage selected, it is anticipated that comparison and coordination of the results of the Watershed Model and the

PLRE-STS can result in technical improvements to both, and to improvements in their application to future projects.

9.4 MM5 Refinement

The MM5 dataset is a very powerful tool that greatly simplifies data entry needs while providing project specific meteorological data for long-term continuous simulations. However, significant limitations in accuracy are recognized in the current MM5 dataset. Revision and recalibration of the MM5 dataset is a recommended improvement highlighted separately within this section because 1) the PAC feels this task is a top priority, and 2) the effort will rely on external development.

The task is a top priority because a revised MM5 dataset is foreseen as the meteorological input for both the PLRE-STS and the LSPC Watershed Model. This work is highly specialized and will require the expertise of scientists at the University of California, Davis to complete. Consequently, completion of this task predominantly relies on external factors and will be developed outside the scope of the PLRE-STS. After completion of this external task, a revised MM5 data set can be pre-processed and included in the meteorological directories to run the SWMM engine of the PLRE-STS. Work on refinement of MM5 is anticipated to begin in the next few months, and to be completed by the end of 2006.

9.5 Recommended Improvements

This section lists recommended improvements to the methodology and the computational tools. This includes both technical improvements to ensure the results are as reliable as possible and user-interface improvements to facilitate the use of the tool. The recommendations are made for the long-term, recognizing that near-term improvements will be constrained by schedules, available funding, and data and methods that are developed outside the scope of the PLRE-STS. For each category of improvement listed, more than one phase of improvement may be needed. This section does not attempt to define these phases. Further, general priorities and sequences of development are apparent in the recommendations, but specific prioritization has not been attempted here.

9.5.1 Technical Improvements

The reader is cautioned that some of the technical improvements listed are complicated endeavors and phasing of improvements or only partial completion of tasks may be feasible in the near-term. The majority of technical improvements relate to the simulation of complex physical processes and the improvement of these techniques will rely to varying degrees on available data and external efforts.

<u>Improvements to spatially distributed source control technique</u>

a. Currently, spatially distributed source controls are subjectively awarded a credit based on statistical information from a standard Z-table. Consider using statistical distributions based on coefficient of variation, percentiles, or an alternative method.
b. Consider using data from other geographic areas to represent future conditions with source controls.

c. Evaluate and potentially incorporate methods to quantify and compare mitigation of pollutant load generation from various road shoulder stabilization techniques (i.e. curb and gutter vs. vegetated swale, etc.)

Improvements for specific source accounting

a. Develop rainfall energy factor (*R*) in the USLE method for disturbed area erosion that uses Tahoe specific meteorological data. Current *R* value does not consider project location and associated orographic effects.
b. Develop more refined methods to estimate gully erosion. Current method is based on best professional judgment or historical evidence of gully advancement.
c. Improve methods and guidance for estimated the delivery ratio of specific sources to the outfall of a catchment.

Improvements for storm water treatment BMPs

a. Consider development of methods to estimate BMP effluent concentrations that are dependent on hydraulic loading for all priority pollutants. The current PLRE-STS uses hydraulic loading for sedimentation but uses empirical effluent concentrations for nutrients.
b. Consider simple kinetic type equations that incorporate the effects of influent quality on performance and could, in principle, be used to analyze treatment trains.
c. Evaluate Tahoe Basin specific effluent concentrations versus National Database effluent concentration values. Evaluate applicability of data from Caltrans and other large storm water management programs from outside the Tahoe Basin.
d. Account for removal of fine particles by vegetation and other non-Stokes Law driven processes.

Improve methods that account for private property BMP implementation

More robust methods are needed to account for the effects of BMP implementation on private property. The current methods rely on a lumped-parameter approach for catchment representation which do not allow for detailed assessment of private BMP implementation. Future refinements should distinguish private BMP implementation amongst land use categories, including methods to vary and evaluate proposed levels of private BMP implementation within each land use category.

Improve representation of maintenance effects

Itemize maintenance requirements/effects and incorporate specific maintenance actions into the methodology, including possibility of reduced performance in future if maintenance not conducted.

Improve representation of infiltration (both inside and outside BMP)

Current infiltration representation both inside and outside storm water treatment BMPs are static and do not consider antecedent conditions. Develop methods that allow for varying infiltrations rate over time and in consideration of antecedent conditions.

Improve hydraulic routing in BMPs

Develop better hydraulic routing of BMPs that relates to actual conditions. Current bypass/treated volume method uses simplifying assumptions and does not accurately represent hydraulic routing in real-world Tahoe Basin BMPs.

Develop methods for application of flow-duration information

Develop a method that, based on sensitivity of streams subject to discharge, uses the pre vs. post project flow-duration statistics for estimating erosion potential downstream of the catchment outlet, and implication on loads to Lake Tahoe.

Incorporate updated Soil Survey into the PLRE-STS

After release of the updated Soil Survey, incorporate new methods into the PLRE-STS for estimating soil properties within a drainage catchment that uses and compliments updated Soil Survey data.

Develop GIS based applications

To take advantage of recent advances in numerical modeling and spatially distributed data availability, a more sophisticated methodology could be developed. This methodology would merge Geographic Information Systems (GIS) with numerical watershed water quality modeling. Development of a methodology based on this concept, while retaining a reasonable level of application complexity for Tahoe Basin implementers, will involve a significant investment of time and resources.

Simulate multiple catchments and routing.

Develop simulation model allowing routing flows and pollutant loads between multiple drainage catchments.

9.5.2 Usability Improvements

The majority of usability improvements outlined in this section are relatively straight forward tasks that involve mechanistic upgrades to the user interface and supporting software code of the PLRE-STS. In contrast to the technical improvements, most of the usability improvements are feasible for completion in the near-term.

Provide clearer reporting and review tools

This will assist with review and help clarify proper application.

a) Develop reporting tools that identify reasonableness of input data and identify if default values were changed by the user.
b) Build in capability to simultaneously review source control implementation effects relative to existing condition pollutant load.
c) Develop capability to compare output from pre-project conditions with multiple project scenarios in one report or review method (i.e. existing conditions pollutant loading compared to pollutant loading for alternatives 1, 2, 3…n).

Develop an abbreviated user’s manual

A brief user’s manual is needed that includes guidance for performing a simulation, data collection, estimating reasonable input parameters, and understanding output. Currently, the spreadsheet tool contains a help file that simply defines each field and parameter contained within the PLRE-STS. Additional guidance includes the following:

a) Recommendations for changing default time-steps when needed.
b) Pollutant load delivery ratio methods. The user is currently required to estimate the amount of pollutant loading from a source delivered to the outlet based on best professional judgment.
c) Provide guidance on the application and combination of spatially distributed source accounting and specific source accounting for the pollutant load generation methodology.
d) Provide guidance on interpretation of results considering absolute and relative accuracy, and use of sensitivity tests at project scale.

<u>Provide more automated error checking within the PLRE-STS</u>

The current format of the PLRE-STS has a minimal amount of error checking. A user could currently misapply the tool in many ways without notification or warning.

a) Develop a method for restoring defaults in case the user unintentionally overwrites them.
b) Add more warning messages and logic checks for input data entry.
c) Add a warning if the user changes hydrologic parameters. In this case, SWMM needs to be run again before viewing output.
d) Develop continuity check criteria for acceptable water balance errors within the SWMM simulation.
e) Sign macros to avoid security issues with running macros.

<u>Form enabled data entry.</u>

Develop a series of forms that would "walk" the user through the data input and provide better data validation and error checking techniques.

9.6 Initial Testing and Parameter Verification

Initial testing and parameter verification should be performed by a small team of technical specialists familiar with SWMM and the PLRE-STS. The initial testing would evaluate the relative accuracy of results from the PLRE-STS compared to actual monitoring data. Due to the average annual format of output within the PLRE-STS only long term monitoring data sets that can be compiled into annual estimates of meteorology, hydrology, and pollutant loading will be applicable. Comprehensive monitoring data as just described is extremely limited, and assumptions will need to be made in many cases to extrapolate and compile monitoring data into annual estimates. This will add an additional layer of uncertainty to the testing process.

Parameter verification would test and refine default parameters used within the PLRE-STS for the various components of the methodology based on comparisons to monitoring data. This parameter verification would include sensitivity analysis to determine recommended ranges of values for parameters as well as an evaluation of relative accuracy if parameters are modified.

<u>Develop a tool for creating rainfall and temperature interface files.</u>

A tool is needed to simplify the meteorological pre-processing. Only a highly advanced user of SWMM would be able to pre-process and apply meteorological data other than the current MM5 data set, which is not recommended for verification purposes. Furthermore, it is highly unlikely that a revised MM5 data set will be available prior to the initiation of testing and refinement. Therefore, multiple site specific meteorological data sets (e.g. NCDC or SNOTEL) will require pre-processing for use in parameter verification and validation of the PLRE-STS.

<u>Verify and adjust PLRE-STS default parameters using Tahoe Basin monitoring data.</u>
The spreadsheet tool needs verification and validation of hydrology and pollutant loads to test and evaluate the tool's general accuracy and robustness. Potential monitoring data sources initially identified include the Tahoe City Wetlands monitoring study, Kings Beach monitoring study, and various Desert Research Institute (DRI) monitoring studies.

<u>Test applications at the project scale</u>
Testing of the methodology at the project scale will help define the appropriate application of the PLRE-STS to typical project conditions, and help define a process for its use in estimating pollutant loads for the purpose of evaluating alternatives in storm water quality improvement projects and estimating load reduction credits. Recommendations or prototype templates that may result from this work include generation of comparison tables for alternatives, generation of load reduction output reports for review by regulatory and grant-funding agencies, and guidance for interpretation of sensitivity and accuracy in the results.

<u>Evaluate applicability of default EMCs</u>
Data from the 16 TMDL storm water monitoring sites used to develop the default EMCs that drive the spatially distributed pollutant load generation within the PLRE-STS should be reviewed. Results in the PLRE-STS using the default EMCs should be compared to results from site specific TMDL storm water monitoring locations. This will help test both the methodology and check the EMC values that were derived from the TMDL data. Additionally, the land use conditions (as defined in this report) of the TMDL storm water monitoring sites should be reviewed to identify the typical land use conditions of these monitoring locations.

9.7 Beta Version, Testing, and Additional Refinement

Release of a beta version of the PLRE-STS will signify the tool is ready for application by general project proponents to test methods and procedures under a wide array of varying project conditions. This beta testing step will need to be performed using a structured process and reporting program in order to advance the applicability of the PLRE-STS. The reader is reminded that a continuous improvement cycle will be necessary and after beta testing the PLRE-STS additional refinement will be necessary based on the beta testing results and external supporting efforts such as the IWQMS and BMP design manuals.

<u>Produce beta version of PRRE-STS</u>
Combine recommended refinements listed in previous sections into a computational tool that has undergone sufficient testing and development to be released for independent application and testing by intended users at the project scale.

Develop structured process for beta testing

A structured process for beta testing by project proponents should be developed. This process and the beta testing program in general will need to provide user support and training, documentation, as well as a structured feedback and commenting format in order to advance the PLRE-STS through additional refinement.

Beta testing by project proponents

Testing of the PLRE-STS by project proponents will help evaluate the usefulness and general applicability of the PLRE-STS to varying project conditions.

Incorporate recommendations and external efforts for additional refinement

The beta testing process will reveal additional needs for refinement to the beta version of the PLRE-STS under varying project scenarios. Recommendations of refinement developed from the beta testing process should be combined with recommendations from the IWQMS and the development of BMP design criteria. A continuous improvement cycle using these three sources of refinement may eventually lead to a release version of the PLRE-STS applicable to water quality alternatives evaluations and TMDL crediting.

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